DETERMINING PUNCHING SHEAR STRENGTH AND PERFORMANCE OF TUBULAR JOINT MODELS

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CERTIFICATION OF APPROVAL

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Approved by,

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July 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ONG KEE HUI

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Special thanks to all of my family and friends for their endless support and encouragement financially, mentally and spiritually.

ABSTRACT

This report presents the integrated progress of the study on the effect of types of tubular connections onto the punching shear capacity. In various cases, punching shear failure is the common steel jacket structure failure factor. This project studies the association of the connection types as the main parameter to the punching shears capacity of the joints. The scope of the project is extended to study the effects of brace-chord angles onto the joint performance and the economic perspective of joints fabrications. SACS modeling and simulations were implemented to obtain the parametric analysis of the joints behavior and the ultimate strength of the joints. Through this study, types of joints that are superior to punching shear stress have been identified. The study has also established the critical brace-chord angle regions and the relationship between the chord stresses and the punching shear strength. The economic benefits of joint optimization are explicated through the fabrication cost analysis. Further extensive study is recommended to indicate other parameters influencing the strength behavior of the joint models.

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CHAPTER 1
INTRODUCTION

1.1 Background Study

With almost 30% contribution of offshore oil and gas resources to the total energy consumed by human, offshore structures have been critically studied throughout the years to improve the integrated process of extracting the resources. Steel tubular structures are commonly installed for the exploration and production of oil and gas from the sea bottom. Despite the progressive development of the offshore platform designs in the industry, the "jacket" or "template" platform remains as the most popular structure in shallow and moderately-deep water area.

Tubular members are typically selected as they possess the qualities that are essential in designing effective steel structure for offshore installation and utilization. They are hollow and could efficiently produce buoyancy during installation. Furthermore, relatively to other geometries, tubular members are superior in the aspects of torsional strength, symmetrical in the cross sections, feasibility and economic feature for connections welding. Generally, tubular connections of jacket structures are the nodal locations where large through members, the chords are connected to the incoming branch members, the braces. Numerous tubular joint models such as T, K, N, Y, X and overlapped joint types are being used in the industrial practices. According to previous research, these joints vary from one another in behaviors exclusive to individual type of joint.

Basically, there are two major methods of studying the behavior of the different types of connections which are (1) analytical virtual models for simulating the real scaled connection characteristics and (2) empirical relations from experimental results of each connection. The relationship between both results would verify the consistency and accuracy of the component results.

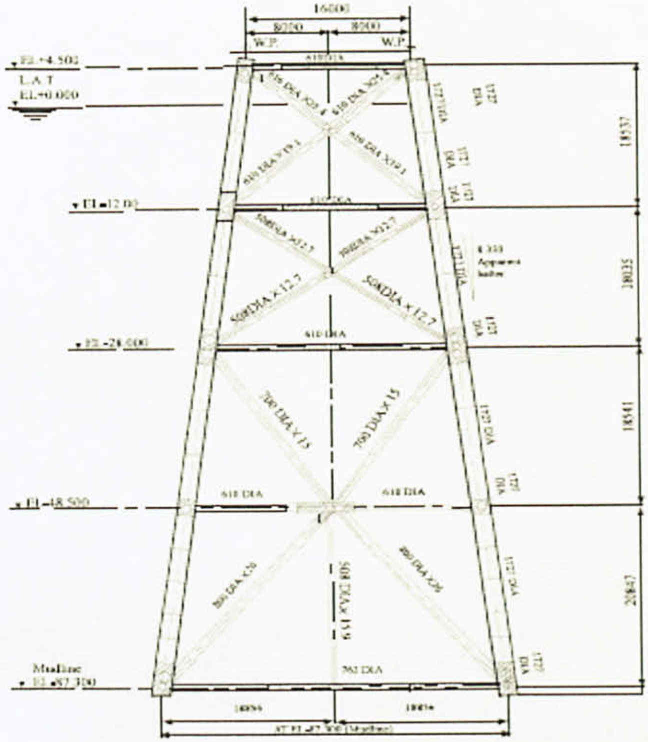


Figure 1.1: General Configuration and Member Size of a 2-D Jacket Frame

1.2 Problem Statement

In an offshore structure design, one of the most critical concerns is the jacket joint. Over the years, the failures of joints are among the most common failure occurred in steel jacket platform resulting in great losses. One of the most regular modes of tubular joint failures is the punching shear failure which usually occurs in the chords due to intense punching loads from the braces. In an occurrence of a jacket platform failure, massive resources are spent just to indicate the locations of the failure due to the immense amount of members and connections of a jacket. The expensive and highly technical repairing works would further amplify the losses in a punching shear failure. Ultimately, this would increase the cost of the operation of the platform as well as reducing the efficiency of the operation. Despite the progressive development of the industry, there are still large uncertainties in the association between the types of tubular joint with the punching shear strength.

1.3 Objectives

The main focus of this project is to determine the quantified effects of tubular joint types onto the punching shear strength. The findings from the study could assist engineers to reduce the time to locate affected joints in an occurrence of a punching shear failure. This is achieved by prioritizing the joint failure verification analysis for the most vulnerable of least performing types of joints based on the parameters analyzed. The established correlations in this study would also be useful in optimizing the joint designs for offshore structures. The scopes of the study covered are as follow:

- Effects of chord stress on joints punching shear stress capacity
- Effects of brace-chord angles on the punching shear stress
- Economic analysis of joints fabrication

CHAPTER 2
LITERATURE REVIEW

2.1 Geometrical Definition

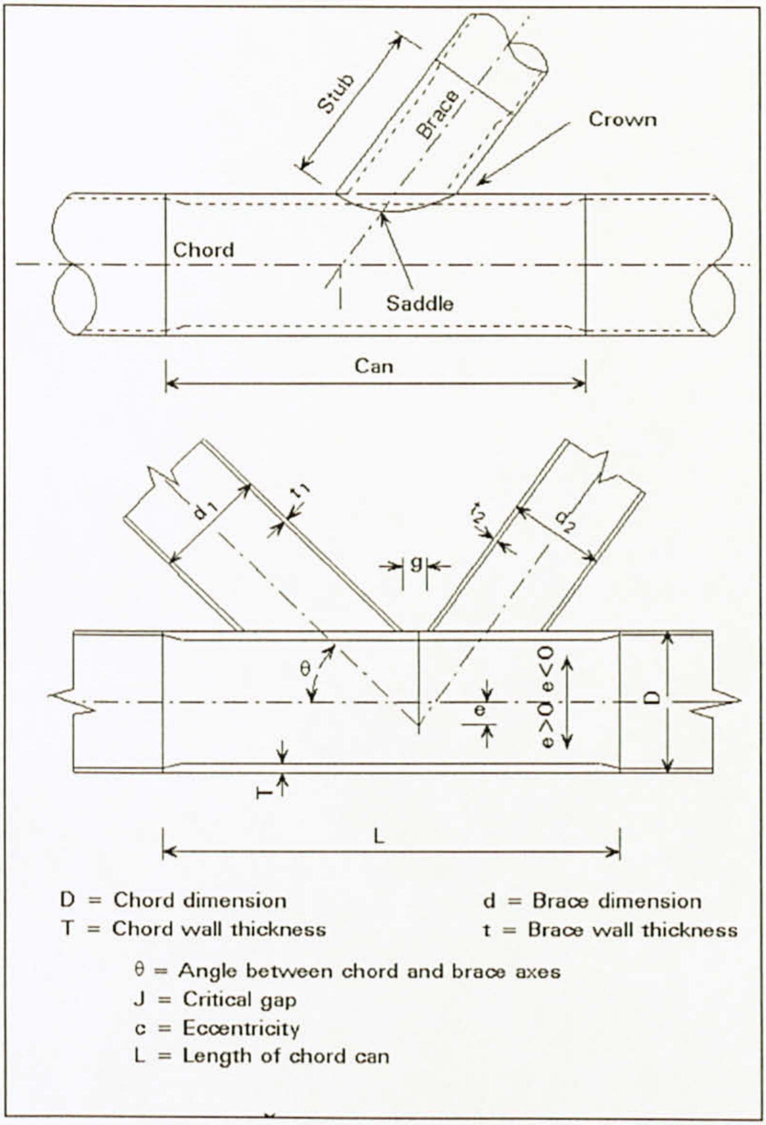


Figure 2.1: Geometrical Definitions

Referring to Figure 2.1a, the following is the list of the geometrical definitions:

L is the length of the chord can

D is the chord outside diameter

T is the chord wall thickness

d is the brace outside diameter

t is the brace wall thickness

g is the gap between the weld toes

e is the eccentricity

θ is the angle between brace and chord axis

The non-dimensional variables used for the parametrical analysis are such as the following:

$\alpha = 2L/D$	Chord slenderness ratio
$\beta = d/D$	Brace to chord diameter ratio (always ≤ 1)
$\gamma = D/2T$	Chord slenderness ratio
$\tau = t/T$	Brace to chord thickness ratio
$\zeta = g/D$	Relative gap

2.2 Types of Offshore Structure Tubular Joint

Tubular joints are one of the critical elements of an offshore steel structure due to the exposure to multiple loadings and the strength deterioration of non homogenous connections of the braces and chords. In the industrial practice, several models of tubular joints are commonly applied such as the T, K, N, X and overlapped joints. These models of tubular joints vary from one another in different particular behaviors.

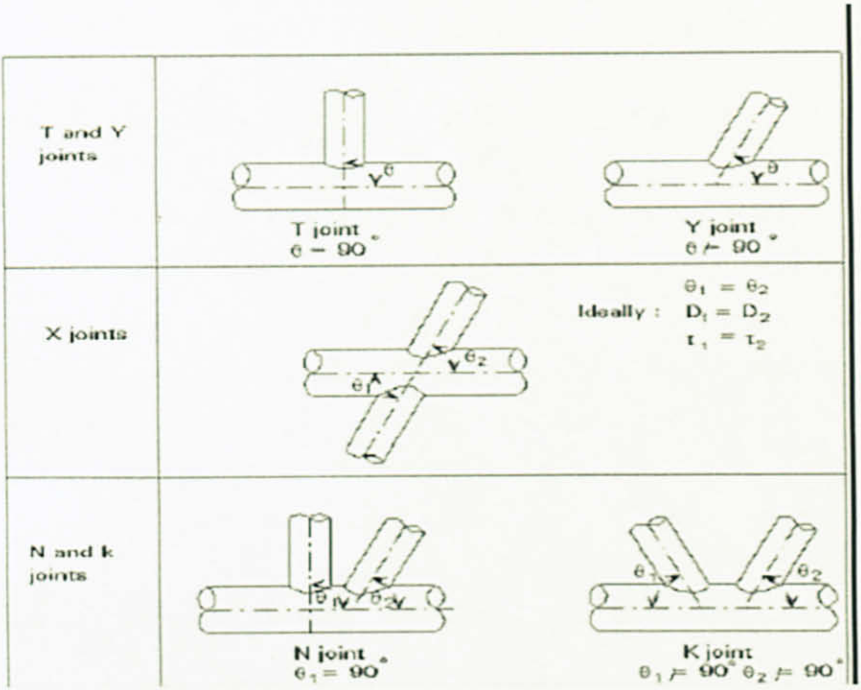


Figure 2.2: Type T, Y, X, N and k tubular joints

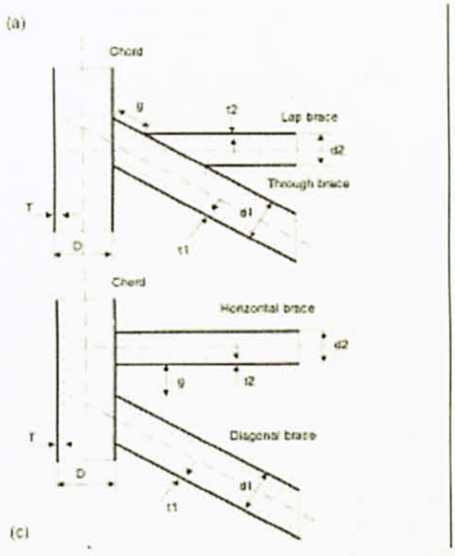


Figure 2.3: Completely overlapped joints and Conventional gap N-joints

2.2.1 T-joint and Y joint

T joint is made up of a single brace which is perpendicular to the chord. The axial force acting in the brace is reacted by bending in the chord. Whereby, a Y-joint consists of a single brace connected at an inclined angle to the chord resulting in an axial force and bending moment reactions in the chord.

2.2.2 X-joint

X joint includes two coaxial braces on either side of the chord. Axial loads from the braces are balanced by the reactions from the opposite members. An ideal X joint have the same diameter and thickness, reducing the possibility of moment development and imbalanced reactions in the local connection. In fact, the variations of members in other consideration such as the brace length may influence the difference in other design parameters such as the inclination angles and brace diameters to minimize the rotations and imbalanced reactions. Forces balance is a critical criterion of consideration for X joint connection. Thus, if the axial force in one side of the brace is significantly larger than the opposite members, the joint could be classified as Y or T joint rather than X joint. On contrary, cases that the perpendicular load components are reacted across the chord could be treated as X joint connection.

2.2.3 N-joint and K joint

N-joint and K-joint comprises of two braces respectively. One of the braces of N joint may be perpendicular to the chord while both of the braces of K-joint are inclined. The ideal load pattern of these joints is achieved when the axial forces are balanced in the braces resulting in significantly low net force in the chord member.

In the logic of the recommended classification scheme of API RP2A, Recommended 21st edition, 2000, members whose axial load component perpendicular to the chord is essentially balanced by axial loads in other member of the same side of the joint are treated as K joints. (Pecknold D, 2007).

2.2.4 Overlapped Joint

Overlapped joint is basically comprises a chord, a through brace and a lap brace. The through brace directly joins the chord whole the lap brace fully welded onto the through brace face leaving no gap in between the lap brace and the chord as what conventional gap joints have. A gap size on the through brace between the outer faces of the lap brace and the chord allows the welding, non destructive test and inspection of joint to be conducted with less complication. (C.K. Soh, 2000).

It has been shown through several recent research studies that tubular joint with complete overlap of braces provides less complicated fabrication than partial overlap joints and better strength behavior than conventional simple gap joints. A recent study conducted in the Heavy Structure Laboratory, Nan Yang Technological University onto the two large-scale completely overlapped tubular circular hollow sections (CHS) joint specimens tested to failure under static monotonic and cyclic loading shows that the ultimate capacity of the joint was discovered to be 7.3% higher than that of the simple gap K- joint. (W.M. Gho Y. F., 2006). Additionally, overlap K-joints in a frame shows higher performance in terms of residual capacity and ductility than simple gap K-joints. Moreover, conventional connection configurations are very costly to be fabricated as compared to the alternative completely overlapped joints. According to the project analysis, the fabrication cost of the innovative eccentric jacket structural which is configured by completely overlapped joint model is greatly reduced as compared to the conventional X-braced structures. (F.Qin, 2001).

This is supported by the study done by (C.K. Soh, 2000) that completely overlapped joints have demonstrated merits in less complicated fabrication and to have higher static strength than the conventional simple gap joints. The potential damage locations of the tubular connections could be shifted to the braces from the chord members, reducing the risk of stability deterioration of the structure especially due to extreme conditions such as strong seismic excitation and collision by tankers. In comparison to N-joint, completely overlapped joints performed better under seismic loadings. (F.Qin, 2001).

However, despite of the advantages of overlapped joints, their behaviors are more complicated than conventional gap joints due to the presence of hidden welds and complication of mechanisms. The failure of overlapped joints could be associated with the premature failure of brace due to local buckling with complex bending deflection in the chord wall.

2.3 Static Strength

The loads considered in joint static design strength are the axial force, the in-plane bending moment and the out-of-plane bending moment for each brace. The other components, which are transverse shear and brace torsion moment, are usually neglected since unlike the preceding loads, these loads do not induce bending in the chord wall. Nevertheless, their presence must never be forgotten and in some specific cases, their effects must be assessed. The axial load, in-plane and out-of-plane bending moments are normally the dimensioning criterion for tubular joints. (Y.S Choo, 2004)

2.4 Punching Shear Failure

Joints of an offshore are formed at location where cross members of braces are welded onto the main leg of the structure or the chords. Under design wind and wave loadings, the forces in each brace are observed to be transmitted directly to the wall of the chord. The possibility of punching shear failure through the wall of the chord exists if the thickness is too small.

According to API 5l, Specification for line pipes, 39th edition Washington, DC: American Petroleum Institute; 1991, the adequacy of the joint may be determined on the basis of the punching shear which would indicate the equivalent results necessary for the connection design. To ensure safety against the punching shear failure of the connection, it is necessary that the shear stress to be less than the shear yield stress of the material, with a suitable safety factor which is provided of being 0.4 times the tensile yield stress.

2.5 Effects of brace-chord angle

As the focus of this study is to establish a relationship between the types of tubular connections to the punching shear capacity, the main analysis parameter that is considered is the brace angle, **θ**. The brace-chord intersection region varies with changing brace inclination angle, **θ**. In the design recommendations provided by API RP2A, Recommended 21st edition, 2000, this change in the region is assumed to affect the joint strength through sin **θ** term in the strength equations. However, the change in the intersection region alters the stress-state of the chord material. Hence, the increase in the brace-chord intersection area does not proportionally contribute to the effective load transfer in the joint. (Y.S Choo, 2004)

The strength reduction for low ***θ*** under compressive chord stresses is anticipated to be more significant as compared to high ***θ*** joints. On the other hand, the tensile chord stress is expected to have less detrimental effect on the strength. The additional compressive chord load acts together with the resolved horizontal brace load and this leads to a detrimental effect. Conversely, for joints under tensile chord stresses, the tensile chord load balances part of the resolved brace horizontal force, and the joint strength is enhanced (Y.S Choo, 2004).

2.6 Effects of chord stress

The chord stress effect is still one of the topics in the offshore industry that is lack of both numerical and experimental databases. In most of the current design guidelines, the geometric dependence of the chord stress effect has not been incorporated. At the same time, the effect of the tensile chord stress has also been neglected in the design codes. Despite the current practice, numerical studies shows that the effects of the tensile chord stresses can significantly increase the punching shear stress at a joint that can damage the structure. The presence of chord stresses does not appear to alter the joint failure model except for thin-walled joints, where chord wall local buckling close to the brace–chord intersection governs the joint strength. For thick-walled joints, more extensive yielding is noted in the chord wall under increasing compressive chord stresses. (Y.S Choo, 2004).

From API RP2A, Recommended 21st edition, 2000, it is shown that the chord stress influences the punching shear stress capacity of the chord by a factor. The shear stress capacity of the individual component is evaluated separately by utilizing the appropriate factors that take into the account of the chord stress effect.

2.7 Effects of geometrical properties

The geometrical properties of the braces and the chord of a tubular connection could affect the performance of the joint. The static strength of thick-walled X-joints is found to be dependent on the geometric ratios β and γ. For X-joints with small β ratios, significant strength reduction is observed for the chord subjected to tensile and compressive stresses. For X-joints with high β ratios, effect of chord stress is less significant. In general, the effect of γ is not as pronounced as that of β. However, the effect of γ relates to the chord wall stability associated with the compressive chord stress. (Y.S Choo, 2003).

CHAPTER 3

METHODOLOGY

3.1 SACS Modeling and Analysis

Structural Analysis Computer System (SACS) is a well known structural analysis program in the oil and gas industry which is commonly utilized to assist the analysis for offshore structure in various phases such as load out, transportation, installation or upending and in place. SACS also enables the function of simulating the motions during various phases involved. Such criteria have been considered in selecting SACS as the main program to assist the analysis of the research to determine the resultant reactions parametric strength of the tubular joints.

To conduct the study, 2 jacket models that are Platform BOVA-1 and Platform BNVA VENT have been used as the models for the joint analysis. For each model, 2 joints are chosen depending on the suitability of the joints for further analysis. The initial parameters and geometrical properties such as the axial stress, angle to the legs, and diameters of the members extended from these joints are extracted from SACS and tabulated in a spreadsheet. The selected joints are modified by removing specific members to form new types of connections. SACS automatically distributes the axial stresses of the removed members into the remaining tubular members yielding new resultant axial stresses acting on the particular joint.

In this analysis, the specifications provided by the American Petroleum Institute, API RP2A, Recommended 21st edition, 2000 to compute the acting punching shear are adopted. According to API, the punching shear should be calculated by:

$$V_p = \tau f sin\theta$$

Where

f = nominal axial, in plane bending, or out of plane bending stress in the brace (punching shear for each kept separate)

τ = ratio of brace thickness to chord thickness

θ = brace angle (measured from the chord)

The allowable punching shear stress in the chord wall is affected by the types of loading, geometry of the joints and also the presence of the nominal longitudinal stress in the chord. As provided by API, the allowable punching shear stress is computed by:

$$V_{pa} = Q_q Q_f F_{yc}/0.6_\gamma$$

Where

Q_q =factor to account for the effects of type of loading and geometry

Q_f=factor to account for the presence of nominal longitudinal stress in the chord

F_{yc}=yield strength of the chord members at the joint (or 2/3 of the tensile strength if less), ksi (MPa)

γ = ratio of chord diameter to double of chord thickness

The scope of study is extended to study the effects of other parameters such as chord stresses, chord thickness and external loadings onto the allowable joint capacities. According to API, effects of chord thickness onto the performance and capacities of the joints are governed by:

$$Pa = QuQfFycT^2/1.7sin\theta$$

and

$$Ma = QuQfFycT^2 (0.8d)/1.7sin\theta$$

Where

Pa= allowable capacity for race axial load

Ma= allowable capacity for brace bending moment

Qu= ultimate strength factor which varies with the joint and load type

The resultant punching shear stress and the allowable punching shear stress are computed for the selected joint prior and after the modifications. For an example, in an analysis of Platform BOVA1, a joint with KT-joint in the YZ-plane and N-joint in the XZ-plane is selected. The particular joint is modified to yield other types of tubular joints. The following figures illustrate the modification phases of the selected joint:

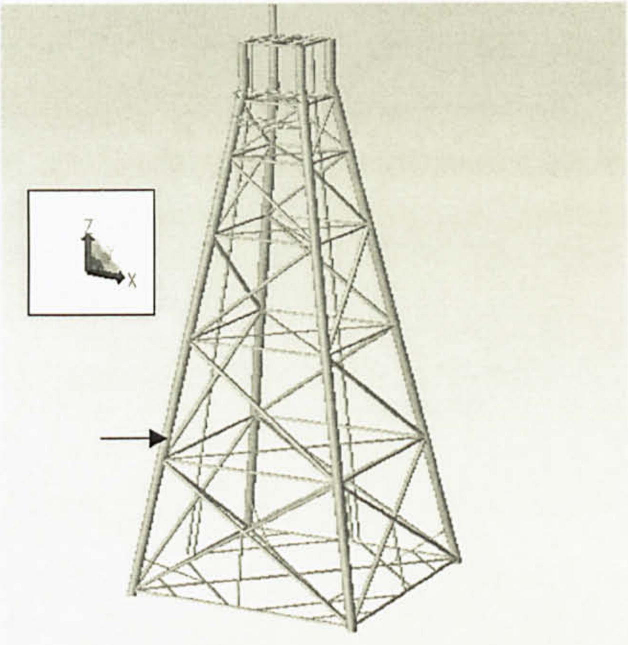


Figure 3.1: BOV-A Jacket Platform

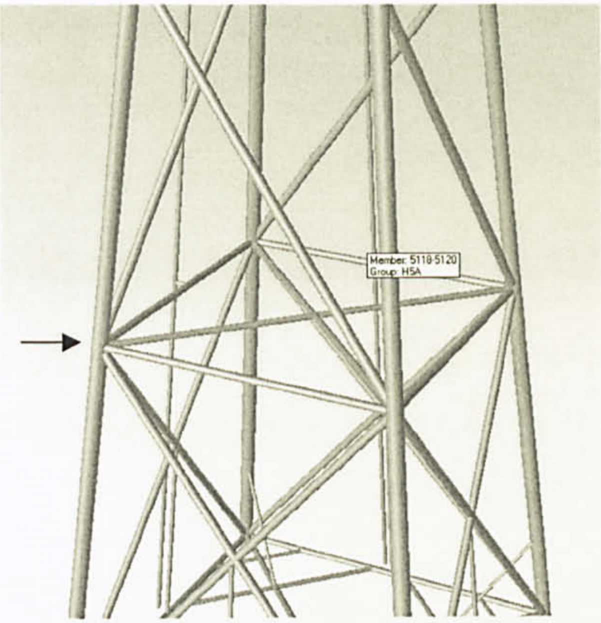


Figure 3.2: Original selected N-Joint in XZ-plane and KT Joint in YZ-plane

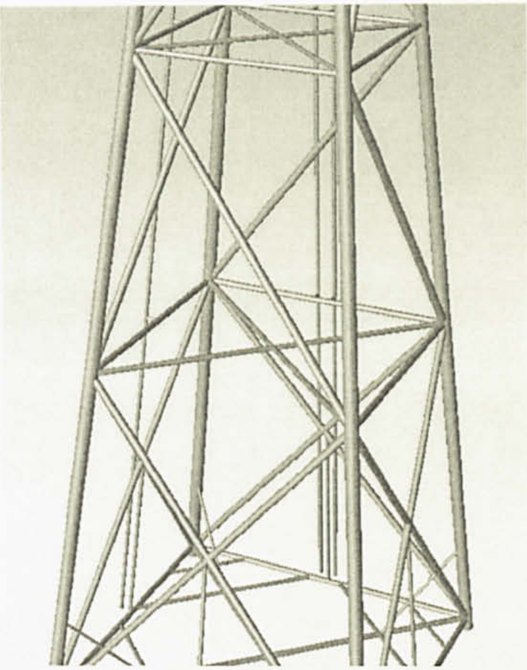


Figure 3.3: Modified Y-Joint in XZ-plane

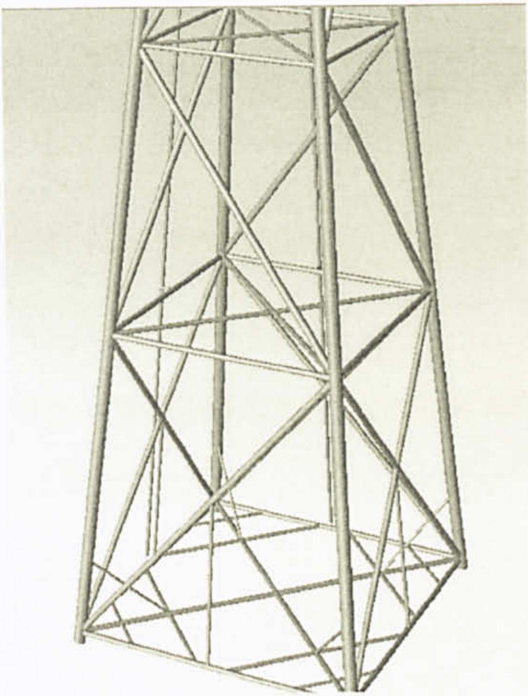


Figure 3.4: Modified T-Joint in XZ-plane

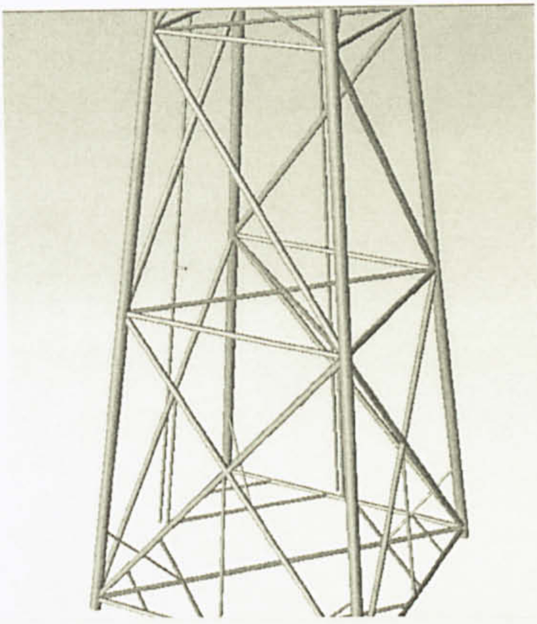


Figure 3.5: Modified K-Joint in YZ-plane

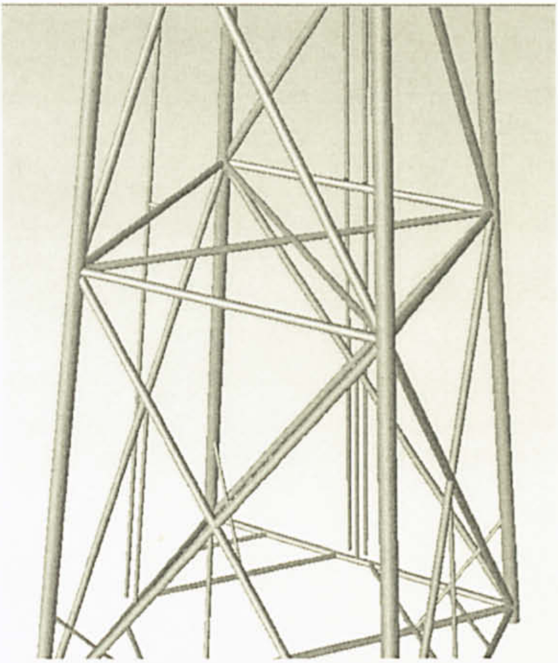


Figure 3.6: Modified N-Joint in YZ-plane

From the complete set of data, the analysis would be performed to indicate the significance of the relationship between the punching shear and the joint types. The analysis is also extended to study the relationship between the joint performance and the specified parameters that are the chord stresses, and brace-chord angles. The performance trends of the different types of tubular joints are established from the analyzed parametrical data and statistic analysis. The established patterns are utilized to conclude the relationship of the punching shear stress with tubular joint types.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 SACS Data Analysis

SACS data for each of the selected jacket models prior and after the modifications are tabulated and analysis is conducted on the data to establish the relationship between the types of tubular joints with the joint performance subjected to punching shear stress. The tabulated data extracted from SACS for selected joints of Platform BOVA1, and Platform BNVA is attached in the appendices.

The first part of this section explains the effects joint types to the punching shear capacity of the joints. It also discusses the influence of chord stress onto the allowable axial stress of different types of joints.

In the following part, the relationship between brace-chord angles and the induced punching shear stress is explained. This part provides detailed graphs and simplified tables to indicate the direct relationship between both studied parameters.

The third part of the section discusses the economic analysis of joint fabrications. The relative costs of fabrications for different types of joints are compared to indicate the economic feasibility of each joint type.

4.2 Effects of Joint Types and Chord Stress on Joint Performance

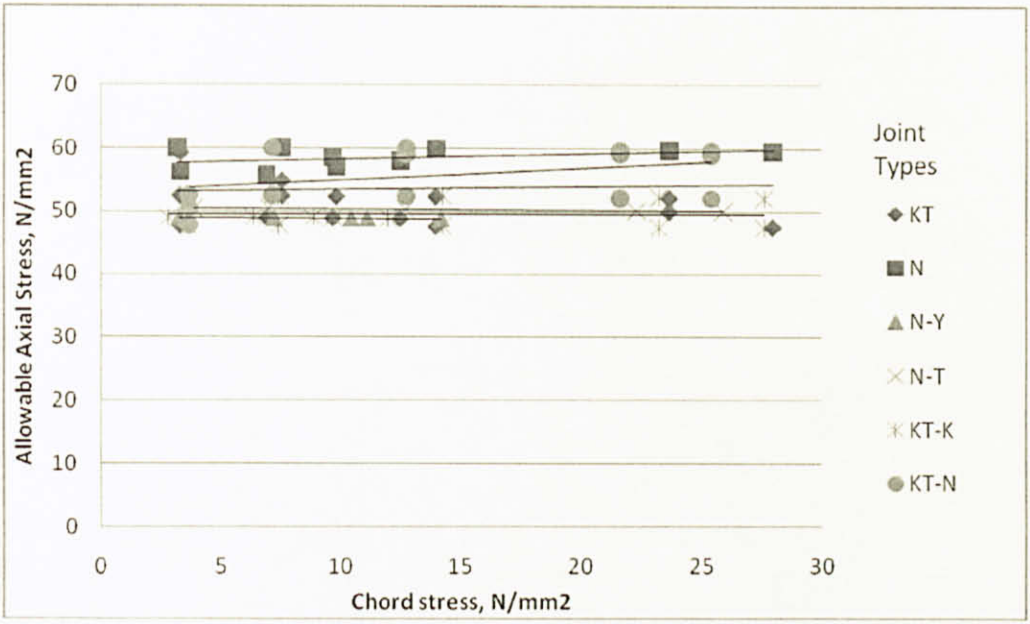


Figure 4.1: Allowable axial stress vs Chord Stress for Different Types of Joints for Platform BOVA1 (Joint 5130)

y KT	$= 0.041x + 53.13$	$R^2 = 0.005$
y N	$= 0.080x + 57.52$	$R^2 = 0.157$
y N-Y	$= -0.010x + 49.01$	$R^2 = 0.961$
y N-T	$= -0.019x + 50.60$	$R^2 = 0.975$
y KT-K	$= 0.006x + 49.50$	$R^2 = 0.000$
y KT-N	$= 0.190x + 53.04$	$R^2 = 0.139$

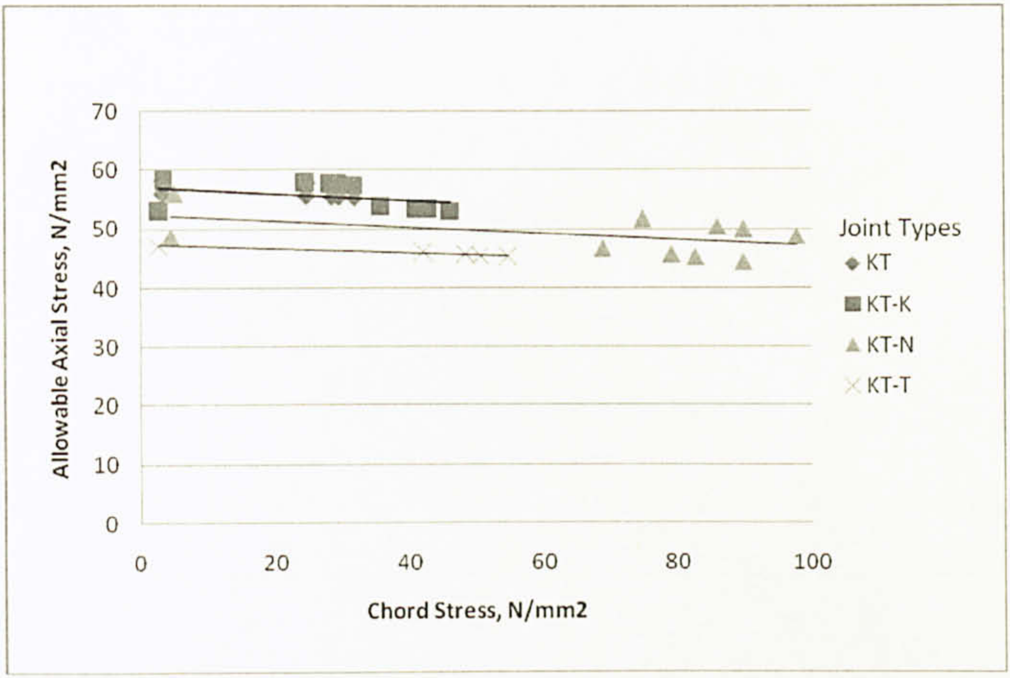


Figure 4.2: Allowable axial stress vs Chord Stress for Different Types of Joints for Platform BOVA1 (Joint 2130)

y KT	$= -0.032x + 60.35$	$R^2 = 0.001$
y KT-K	$= -0.026x + 71.75$	$R^2 = 0.377$
y KT-N	$= 0.178x + 70.59$	$R^2 = 0.122$
y KT-T	$= -0.039x + 61.52$	$R^2 = 0.933$

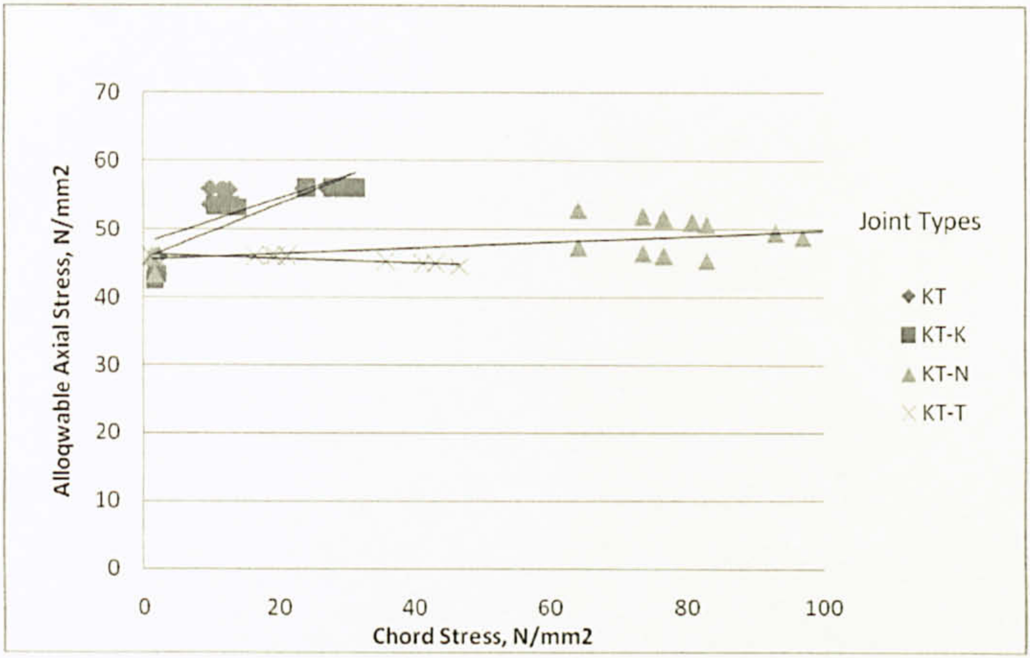


Figure 4.3 : Allowable axial stress vs Chord Stress for Different Types of Joints for Platform BNVA (Joint 6110)

y KT = 0.334x + 47.85 $R^2 = 0.566$

y KT-K = 0.405x + 45.60 $R^2 = 0.738$

y KT-N = 0.041x + 45.67 $R^2 = 0.253$

y KT-T = -0.031x + 46.34 $R^2 = 0.821$

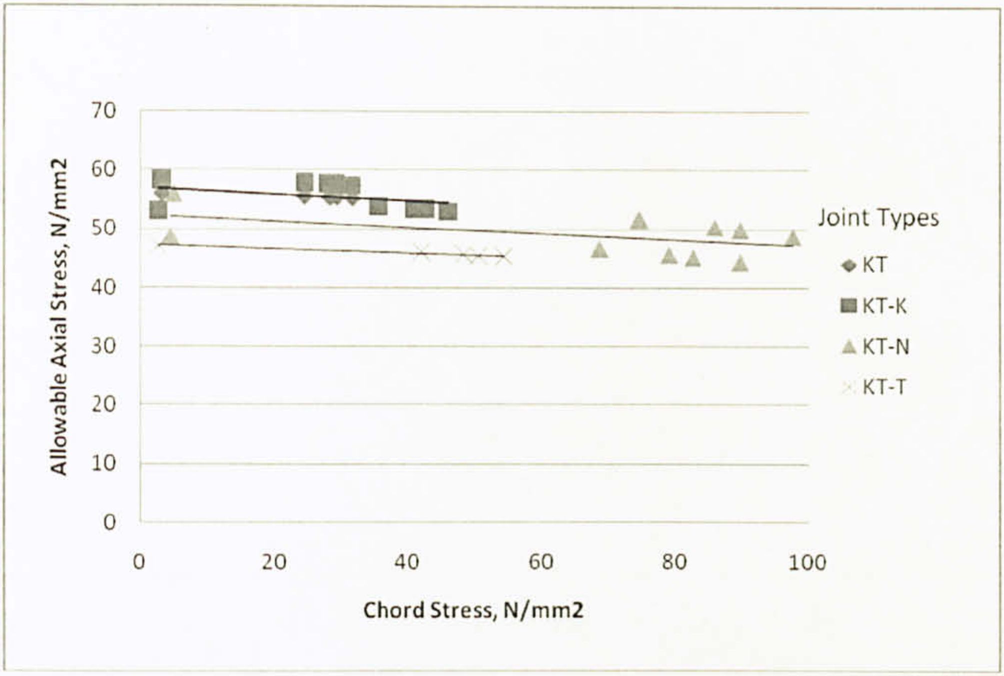


Figure 4.4: Allowable axial stress vs Chord Stress for Different Types of Joints for Platform BNVA (Joint 5130)

y KT	$= -0.050x + 56.90$	$R^2 = 0.143$
y KT-K	$= -0.057x + 57.14$	$R^2 = 0.134$
y KT-N	$= -0.053x + 52.38$	$R^2 = 0.272$
y KT-T	$= -0.034x + 47.30$	$R^2 = 0.972$

Table 4.1: Comparison of Punching Shear Performance of Various Types of Joint for Platform BOVA1

Platform	Joint type	Average linear equation	Average Allowable Axial Stress, N/mm2 (x=30N/mm2)
BOVA-1 (JOINT 5130)	KT	0.041x + 53.13	57.23
	N	**0.080x + 57.52**	**65.52**
	Y	-0.010x + 49.01	48.01
	T	-0.019x + 50.60	48.7
	K	0.006x + 49.50	50.1
	N	**0.190x + 53.04**	**72.04**

Platform	Joint type	Average linear equation	Average Allowable Axial Stress, N/mm2 (x=100N/mm2)
BOVA-1(JOINT 2130)	KT	-0.032x + 60.35	57.15
	K	-0.026x + 71.75	69.15
	N	**0.178x + 70.59**	**88.39**
	T	-0.039x + 61.52	57.62

Table 4.2: Comparison of Punching Shear Performance of Various Types of Joint for Platform BNVA

Platform	Joint type	Average linear equation	Average Allowable Axial Stress, N/mm2 (x=100N/mm2)
BNVA (JOINT 6110)	KT	0.334x + 47.85	81.25
	K	**0.405x + 45.60**	**86.1**
	N	0.041x + 45.67	49.77
	T	-0.031x + 46.34	43.34

Platform	Joint type	Average linear equation	Average Allowable Axial Stress, N/mm2 (x=100N/mm2)
BNVA (JOINT 5130)	KT	-0.050x + 56.90	50
	K	**-0.057x + 57.14**	**51.44**
	N	-0.053x + 52.38	47.08
	T	-0.034x + 47.30	43.9

For platform BOVA1, the cumulative results consistently show that N joint is capable of resisting the largest axial stress comparatively, to other types of joints such as KT joint, K joint, and T joints. Consequently, N joint has larger punching shear strength that makes it less prone to punching shear failure. This implies that N joint is superior in resisting punching shear stress in comparison to other types of joints for the case of Platform BOVA1.

On the other hand, in the case of platform BNVA, K joint shows better efficiency in resisting axial stress. K joint has the largest average allowable shear stress capacity than other types of joints that are KT joint, N joint and T joint. In the case of Platform BNVA, K joint has larger punching shear strength that reduces the possibility of punching shear failure occurrence.

Inconsistent results between the two studied platforms could be due to various reasons such as the environmental loadings, the platform geometries, braces angles and other parameters. Both platforms are located at different areas with different exposure of environmental factors. Geometrically, Platform BOVA1 is a rectangular based platform while Platform BNVA is a triangular based platform. The difference in such factors suggests the difference of the thorough load distribution, hence yielding separate unique results for the respective platform. Therefore, from this particular section of the study, it is discovered that each platform has an exclusive types of joint that is superior in carrying higher capacity of punching shear stress which is influenced by various contributing factors that are particular for each platform.

The study on the graphs also shows that there is no apparent pattern that controls the influence of the chord stress on the average axial stress and consequently, the punching shear stress. Nevertheless, in coherent to the API specification, the punching shear stress is found to be influenced by the chord stress. For thin walled member, tensile chord stress could significantly increase the punching shear stress. The average linear equations indicate the relationship between the chord stress and the axial stress. It signifies the influence of chord stress on the average axial stress for particular joint. The effects of chord stress onto the axial stress under different load conditions for the studied joint could be extrapolated through the equations.

4.3 Effects of Brace Chord Angles on Punching Shear Stress

Table 4.3: Critical Angles for Joint 5130 of Platform BOVA-1

Platform	Parameter	Critical Angles
BOVA-1 (Joint 5130)	Axial Punching Stress	30.83
		45.21
	Out of Plane Bending	45.21
		84.25
	In Plane Bending	30.83
		84.25

Table 4.4: Critical Angles for Joint 2130 of Platform BOVA-1

Platform	Parameter	Critical Angles
BOVA-1 (Joint 2130)	Axial Punching Stress	31.27
		41.17
	Out of Plane Bending	84.23
		41.17
	In Plane Bending	84.25
		41.17
		84.25

Table 4.5: Critical Angles for Joint 6110 of Platform BNVA

Platform	Parameter	Critical Angles
BNVA (Joint 6110)	Axial Punching Stress	30.83
		84.25
	Out of Plane Bending	85.28
		94.41
	In Plane Bending	39.58
		94.71

Table 4.6: Critical Angles for Joint 5130 of Platform BNVA

Platform	Parameter	Critical Angles
BNVA (Joint 5130)	Axial Punching Stress	36.34
		81.93
	Out of Plane Bending	49.82
		81.93
	In Plane Bending	49.82
		81.93

Table 4.3.4a, Table 4.3.4b, Table 4.3.4c, Table 4.3.4d are the compilations of the critical angles for the selected joints for both platforms extracted from the graphs in APPENDIX E- Effects of Brace-Chord Angles Graphs. From these tables, it is discovered that the critical angle regions are **30°-35°, 40°-45°**, and **80°-85°.** For all types of studied joints such as KT joint, K joint, N joint, and T joints, the braces with the angle orientation of these regions tend to impose higher stress combinations onto the chord. Within these regions, all three main studied parameter which are the axial stress, out of plane bending stress, and in plane bending stress that contribute to the punching shear stress at the joint have critical magnitudes. In API, the punching shear stresses are governed by the term, sin θ which is one the main parameter of the study. Generally, the pattern of the graphs represents the typical sinusoidal pattern which explains the influence of the sin θ term in the equation. This also explains the multiple critical regions of brace chord angle that have been identified in the study which is one of the characteristic of a sinusoidal curve. Therefore, ideally it could be

recommended that to reduce punching shear stress induction onto the chord, the braces should be design not to be oriented in these angle regions.

4.4 Economic Analysis

Cost of fabrication is one of the most critical perspectives of evaluating a jacket platform design apart from the technical considerations involved. The fabrication cost of a tubular joint is mainly contributed by the cost of the welding and the material of the members. Redundancy of the members of jacket platform design could significantly increase the cost of the fabrication which consequently inflates the total cost of the jacket platform. Optimization of jacket platform design is when the balance between the safety, efficiency of usage and cost of fabrication is met. In the context of jacket platform joint study, the joint designs are optimized through reduction of redundancy and cost whilst providing sufficient margin of joint strength as the safety factor consideration. Redundancy at a joint could simply be reduced through reduction of brace members which also reduces the cost of welding for the excessive members.

In a joint design, the types of joints will control the cost of the fabrication through the material cost and the welding cost. Each type of joint would provide different combinations of required material volume and the welding length. The fabrication material requirement is controlled by the length of the braces for each joint combination, while the length of welding depends on the number of the braces and the end cross sectional geometry. Relatively, for a typical joint design, the inclined member is approximately$\sqrt{2}$ longer than horizontal member as illustrated below.

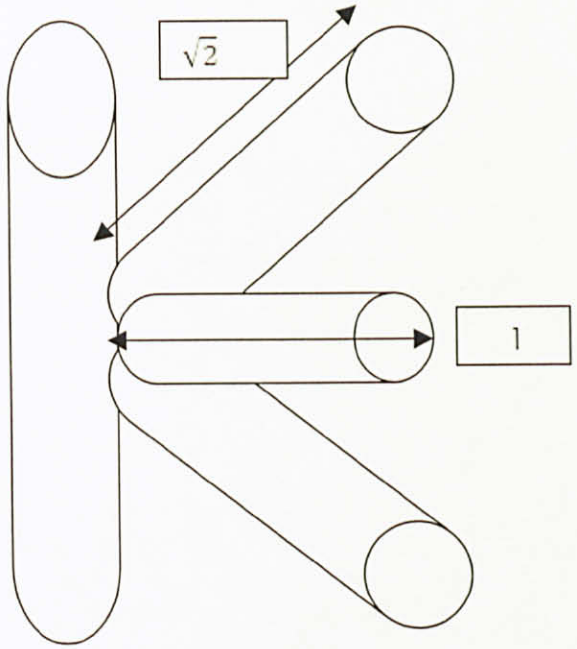
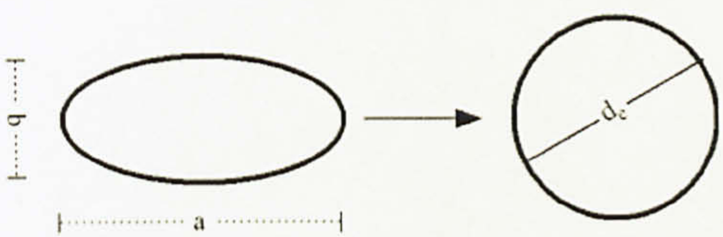


Figure 4.5: Relative length of inclined and horizontal brace members for KT joint

The brace end cross sectional geometries could either be a tube or an elliptical tube depending on the inclination of the brace member. The relationship of the outer perimeters between the circular tube and elliptical tube is explained through Heyt and Diaz simplified mathematical expression.

Oval Equivalent Perimeter

The equivalent diameter of a oval duct or tube (ellipse) can be calculated as (Heyt & Diaz)



The perimeter of an oval duct can be expressed as

$$P \approx 2\,\pi\,(1/2\,(a^2 + b^2))^{1/2}$$

where

P = perimeter oval duct (m, inches)

a = major dimension of the flat oval duct (m, in)

b = minor dimension of the flat oval duct (m, in)

Therefore, if $de = 1$; $a = 1$ and $b = 0.88333$

For this analysis, the relative welding cost is assumed to be 0.5 of material cost to simplify the comparison of costs. The following table and graph show the simplified relationship between the types of joint and the cost of fabrication:

Table 4.7: Cost of Joint Fabrication for Different Types of Joints

Joint	Inclined members	Horizontal members	Total length of braces	Total length of welding	Cost of 1 unit of joint fabrication
KT	2	1	3.828	19.909	13.783
T	0	1	1.000	3.142	2.571
K	2	0	2.828	16.767	11.212
N	1	1	2.414	11.525	8.177
Y	1	0	1.414	8.383	5.606

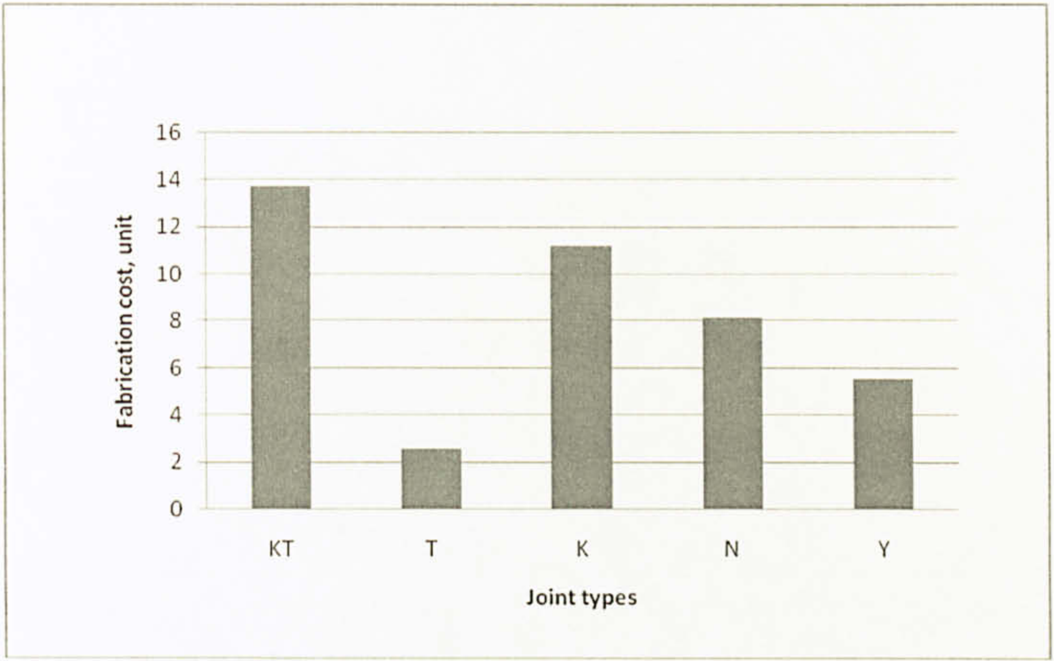


Figure 4.6: Total Estimated Fabrication Costs of Different Joint Types

From the bar graph, KT joint has the lowest fabrication feasibility in the economic point of view, while T joint has the lowest fabrication costs. K, N and Y joint have intermediate cost of fabrications respectively. On the average, the relative cost of fabrication for T joint is 56.22% more economical than the other types of joint. From the study, it is discovered that in several cases there have been of redundancy in the joint design. In such cases, removing the redundant brace members is possible and safe to increase the feasibility of the fabrication. The process of compensating the redundancy of the joint with lower fabrication cost would optimize the design.

CHAPTER 5

CONCLUSION

Sufficient data has been accumulated from the research and literature review to develop reliable comprehension and analytical skills for this study. Primarily, the study has established several relationships that correspond to the objective and the scope of study. The summary of the findings is such as the following:

Effects of Joint Types on Punching Shear Strength

From the first part of the analysis it is discovered that N joint possesses the highest capacity to carry punching shear stress for the case Platform BOVA1. For the case of Platform BNVA, K joint is capable of resisting the largest punching shear stress. In this study, the average allowable punching shear stress capable of being carried by N joint and K joint are 31.79% and 56.85% respectively. The analysis indicates no general decisive types of joint that is most superior to the punching shear stress.

Effects of Chord Stress on Punching Shear Strength

The analysis also shows that the punching shear capacity is partially governed by the chord stresses even though no apparent general relationship between both parameters has been discovered. The established average linear relationship between the chord stress and the punching shear capacity for the studied joints could be used to estimate the reaction of the joint under different chord stresses.

Effects of Brace Chord Angles on Punching Shear Strength

In this study also, the critical regions of brace chord angles have been identified and discussed. The punching shear stresses induced in 3 regions that are 30°-35°, 40°-45°, and 80°-85° are typically higher than other regions. The general pattern of the graphs represents the typical sinusoidal pattern that is due to the influence of the sin θ term in the equation of punching shear stress. Ideally, the braces should be design not to be oriented in these angle regions to reduce punching shear stress induction.

Economic Analysis on Joint Fabrication

The economic analysis shows that the feasibility of the fabrication cost is affected by the types of joints. Joint designs could be optimized by eliminating redundancy to minimize the cost of fabrication. From the study, it is shown that the most feasible type of joint to be fabricated is T joint. On the average, the relative cost of fabrication for T joint is 56.22% more economical than the other types of joint

In conclusion, the project has achieved the objective to quantify the relationship between the types of typical tubular joints of jacket platform with the punching shear strength and joint performance. The project has also covered the extended scope of study which further affirms the correlations between the studied parameters which are the chord stress, brace-chord angle and the economic analysis on the joint fabrication. For future study, the scope of the study could be expanded and more data should input could be analyzed to verify the findings of this study.

CHAPTER 6

ECONOMIC BENEFIT

6.1 Project Expenditure

The basis of the project is data tabulation and analysis on virtual models of selected designed jacket platforms. Therefore, the study of this project has been conducted on minimal expenses. The main financial costs of the project are the expenditures on the literature materials for the reference process and the computer components to enhance the tabulation and analytical works throughout the study. The following is the tabulated representation of the expenses.

Table 6.1: Project Expenditure

Expenditure Item	Amount (RM)	Justification
1. Literature Reference		
• Reading materials (reference books and journals)	RM60.00	Lump sum amount
2. Transportation		
• Travelling to separate places for acquiring project materials	RM70.00	Lump sum amount
3. Computer Components		
• Random Access Memory (RAM) upgrade	RM200.00	To enhance quality of data tabulation work and efficiency of data analysis
4. Miscellaneous		
• Miscellaneous items used	RM60.00	Lump sum amount

for the project (mainly stationeries, printing, hardbound etc)		
Total Amount	**RM390.00**	

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APPENDICES

APPENDIX A-Project Milestones

APPENDIX A.1: Milestone for the First Semester of Final Year Project

APPENDIX A.2 : Milestone for the Second Semester of Final Year Project

APPENDIX A.1: Milestone for the First Semester of Final Year Project

No	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic															
2	Preliminary Research Work -Literature review and information gathering															
3	Submission of Preliminary Report				X											
4	Seminar 1															
5	Project work continues - SACS Modeling - SACS Simulations								Mid-semester break							
6	Submission of Progress Report									X						
7	Seminar 2															
8	Project work continues -Parametric Analysis															
9	Submission of Interim Report Final Draft														X	
10	Oral Presentation															X

APPENDIX A.2 : Milestone for the Second Semester of Final Year Project

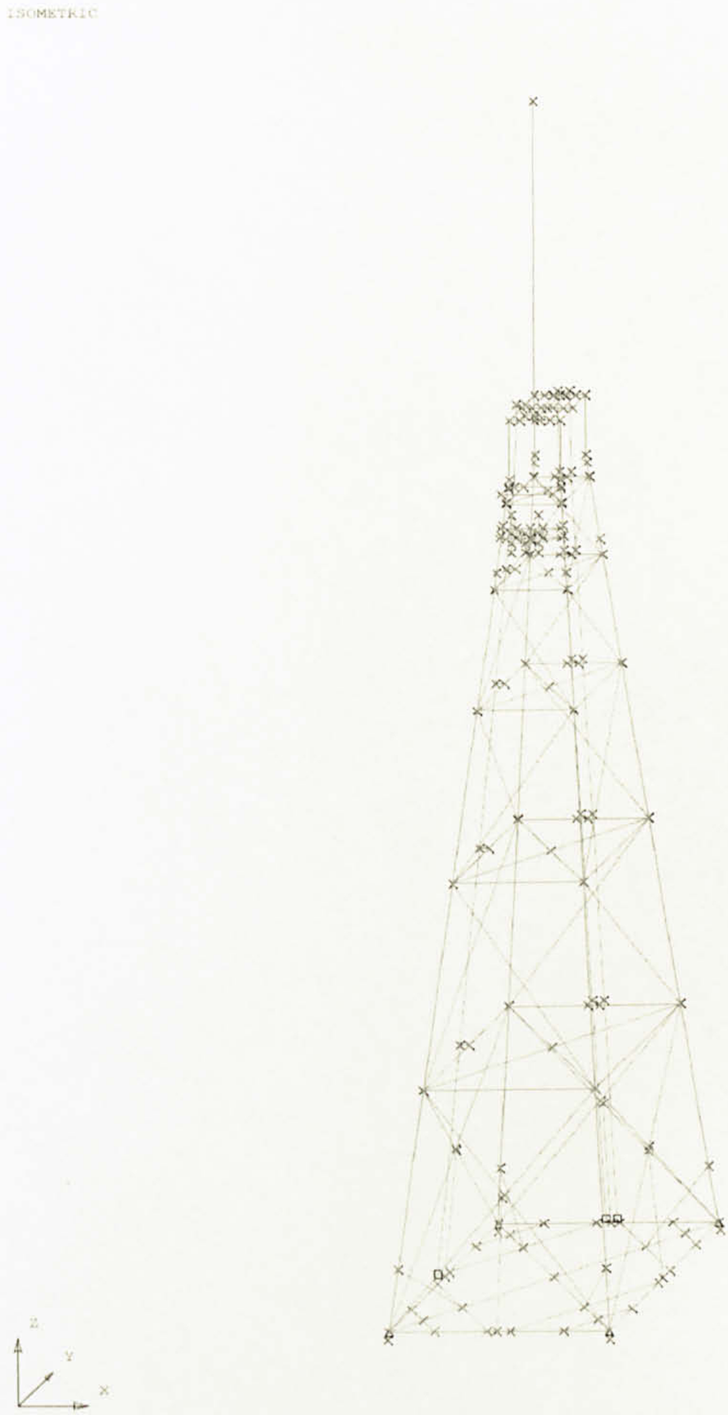
No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Continue with Analysis (SACS Software)														
2	Results gathering and Analysis														
3	Submission of Progress Report						X								
4	Discussion and Conclusion of Project Research														
5	Poster Exhibition										X				
6	Submission of Dissertation (soft bound)												X		
7	Oral Presentation														X
8	Submission of Project Dissertation (Hard Bound)														X

APPENDIX B – SACS Software (Original Models)

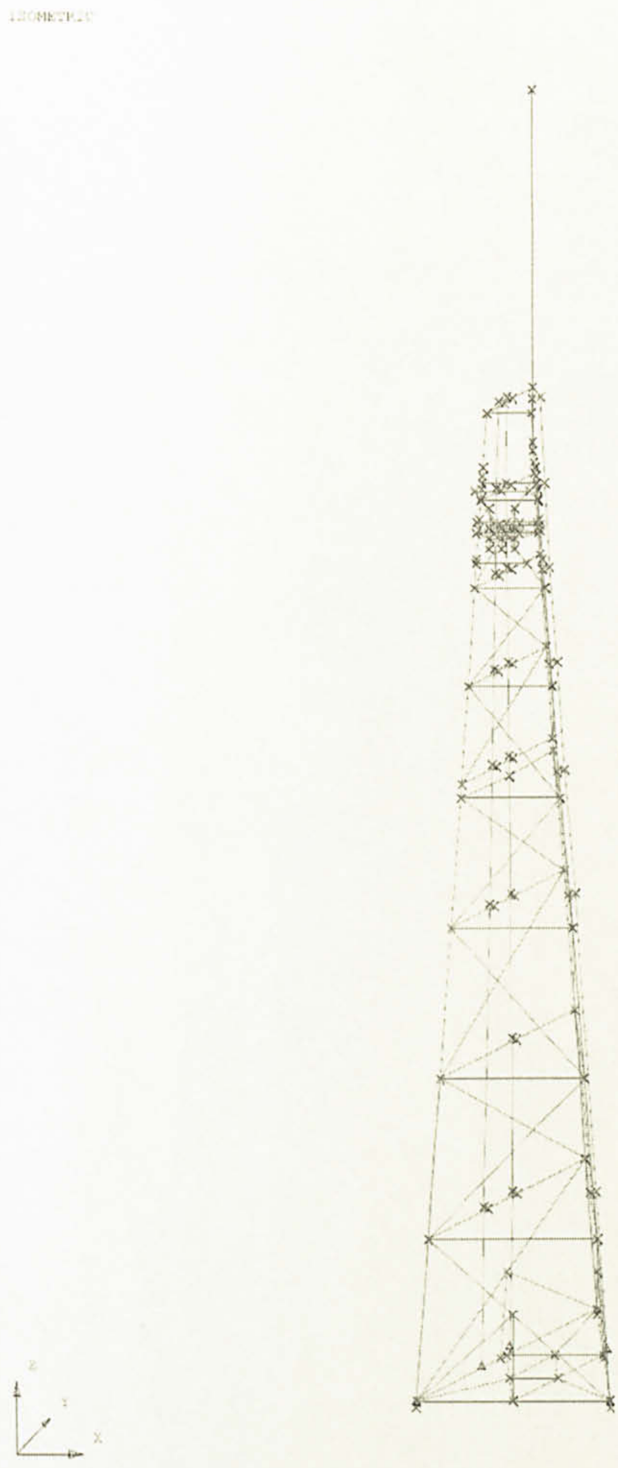
APPENDIX B.1: BOVA1 Platform Model Plots

APPENDIX B.2: BNVA Platform Model Plots

APPENDIX B.1: BOVA1 Platform Model Plot



APPENDIX B 2: BNVA Platform Model Plot



APPENDIX C- Load Combinations

APPENDIX C.1: Load Combinations BOVA1 Platform

APPENDIX C.2: Load Combinations BNVA Platform

APPENDIX C.1: Load Combinations BOVA1 Platform

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
11	11	-1130.522	1132.659	-3081.936	-47288.7	-47362.1	391.316
12	12	849.863	2169.744	-3140.922	-109140	43421.07	-945.571
13	13	2040.313	2022.486	-3149.497	-100552	103310.3	-1479.56
14	14	1823.205	354.429	-3142.621	-12159.8	92410.38	-1009.79
15	15	0	0	-3114.373	-763.029	-559.634	0

APPENDIX C.2: Load Combinations BNVA Platform

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
15	9	1394.833	1123.933	-1284.48	-62575.7	77947.81	-4379.38
16	10	1604.21	1292.557	-1477.16	-71965.1	89653.06	-5036.67
17	11	1673.664	1348.653	-1476.2	-74891.5	93531.96	-5254.9
18	12	1813.249	1461.181	-1474.27	-80775.3	101347.8	-5693.1
19	13	0	0	-1303.71	-3861.79	-123.956	0

APPENDIX D- SACS Output

APPENDIX D.1: SACS Output for BOVA1 Platform

APPENDIX D.2: SACS Output for BNVA Platform

APPENDIX D.1: SACS Output for BOVA1 Platform

BOVA1 (JOINT 5130)

Original Joint (KT Joint and N Joint)

COMMON JOINT	CHORD JOINT	BRACE JOINT	OD	WT	FY	JOINT TYPE	GAP	OD	WT	RD BRACE AN	OAD CAS	CHORD STS	FA	OPB	IPB	FA	OPB	IPB	unity check
5130	4130	4120	83.82	2.54	248	K	10.4	50.8	0.952	30.83	11	7.53	5.79	2.95	1.05	54.85	82.6	132.23	0.129
5130	4130	4120	83.82	2.54	248	K	22.82	50.8	0.952	30.83	12	23.67	10.95	3.07	2.1	50.02	82.23	132.23	0.245
5130	4130	4120	83.82	2.54	248	K	29.19	50.8	0.952	30.83	13	27.99	10.18	10.18	2.54	47.59	82.07	132.23	0.259
5130	4130	4120	83.82	2.54	248	K	30.05	50.8	0.952	30.83	14	13.96	1.64	4.37	0.47	47.63	82.5	132.23	0.068
5130	4130	4120	83.82	2.54	248	T	0	50.8	0.952	30.83	15	3.28	-0.02	0.23	1.47	47.74	82.63	132.23	0.008
5130	5536	5535	83.82	2.54	248	K	-6.81	45.72	0.952	45.21	11	6.88	2.78	2.8	1.47	55.73	86.73	132.23	0.072
5130	5536	5535	83.82	2.54	248	K	22.82	45.72	0.952	45.21	12	9.65	-4.88	9.53	0.31	58.47	86.69	132.23	0.154
5130	5536	5535	83.82	2.54	248	K	29.19	45.72	0.952	45.21	13	12.47	-8.16	11.17	1.33	57.96	86.65	132.23	0.223
5130	5536	5535	83.82	2.54	248	K	30.05	45.72	0.952	45.21	14	9.79	-5.39	5.79	1.22	57.08	86.69	132.23	0.137
5130	5536	5535	83.82	2.54	248	K	0	45.72	0.952	45.21	15	3.15	0.32	0.27	0.32	60.1	86.76	132.23	0.008
5130	5536	5525	83.82	2.54	248	K	-6.81	45.72	0.952	45.21	11	6.88	-2.72	3.41	0.02	48.95	86.73	132.23	0.081
5130	5536	5525	83.82	2.54	248	K	22.82	45.72	0.952	45.21	12	9.65	-9.61	5.04	1.29	48.92	86.69	132.23	0.234
5130	5536	5525	83.82	2.54	248	K	29.19	45.72	0.952	45.21	13	12.47	-11.05	8.88	1.92	48.88	86.65	132.23	0.292
5130	5536	5525	83.82	2.54	248	K	30.05	45.72	0.952	45.21	14	9.79	-4.35	6.66	1.07	52.34	86.69	132.23	0.132
5130	5536	5525	83.82	2.54	248	K	0	45.72	0.952	45.21	15	3.15	0.46	0.38	0.18	59.69	86.76	132.23	0.011
5130	4130	5122	83.82	2.54	248	K	-3.99	40.64	0.952	84.25	11	7.53	-4.95	3.63	5.49	60.06	91.85	132.23	0.119
5130	4130	5122	83.82	2.54	248	K	-3.99	40.64	0.952	84.25	12	23.67	-4.48	9.25	9.25	59.68	91.44	132.23	0.142
5130	4130	5122	83.82	2.54	248	T	0	40.64	0.952	84.25	13	27.99	-2.33	14.4	2.83	59.51	91.26	132.23	0.141
5130	4130	5122	83.82	2.54	248	K	-6.81	40.64	0.952	84.25	14	13.96	1.51	10.22	4.98	59.96	91.73	132.23	0.1
5130	4130	5122	83.82	2.54	248	K	-6.81	40.64	0.952	84.25	15	3.28	-0.56	0.31	6.3	59.25	91.88	132.23	0.04
5130	4130	5140	83.82	2.54	248	K	-6.81	40.64	0.952	84.25	11	7.53	-1.92	3.82	1.43	60.06	91.85	132.23	0.059
5130	4130	5140	83.82	2.54	248	K	-6.81	40.64	0.952	84.25	12	23.67	4.73	5.66	2.46	59.68	91.44	132.23	0.12
5130	4130	5140	83.82	2.54	248	K	-6.81	40.64	0.952	84.25	13	27.99	7.52	8.97	3.44	59.51	91.26	132.23	0.191
5130	4130	5140	83.82	2.54	248	K	-6.81	40.64	0.952	84.25	14	13.96	4.46	6.68	3.84	59.96	91.73	132.23	0.124
5130	4130	5140	83.82	2.54	248	K	-6.81	40.64	0.952	84.25	15	3.28	-0.61	0.15	2.58	56.22	91.88	132.23	0.023
5130	4130	5105	83.82	2.54	248	T	0	35.56	0.952	81.8	11	7.53	-0.74	4.8	0.26	52.44	98.43	132.23	0.045
5130	4130	5105	83.82	2.54	248	T	0	35.56	0.952	81.8	12	23.67	-0.54	1.73	0.53	52.1	98	132.23	0.022
5130	4130	5105	83.82	2.54	248	T	0	35.56	0.952	81.8	13	27.99	-0.41	1.95	1.04	59.51	97.8	132.23	0.022
5130	4130	5105	83.82	2.54	248	T	0	35.56	0.952	81.8	14	13.96	-0.53	4.3	0.59	52.34	98.31	132.23	0.038
5130	4130	5105	83.82	2.54	248	T	0	35.56	0.952	81.8	15	3.28	-0.66	0.09	0.18	52.47	98.47	132.23	0.014

Modified Joint (KT Joint and Y Joint)

COMMON JOINT	CHORD JOINT	BRACE JOINT	OD	WT	FY	JOINT TYPE	GAP	OD	WT	RD BRACE AN	OAD CAS	CHORD STS	FA	OPB	IPB	FA	OPB	IPB	unity check
5130	4130	4120	83.82	2.54	248	K	9.47	50.8	0.952	30.83	11	7.81	5.86	2.89	1.04	55.01	82.59	132.23	0.129
						K	24.18				12	23.84	10.76	2.94	2.11	49.52	82.22	132.23	0.242
						K	30.05				13	28.63	9.88	5.46	2.55	47.26	82.04	132.23	0.253
						K	30.05				14	14.65	1.47	4.2	0.48	47.62	82.48	132.23	0.063
						T					15	2.9	0.01	0.27	1.47	60.1	82.63	132.23	0.008
5130	5536	5535	83.82	2.54	248	T		45.72	0.952	45.21	11	7.2	1.96	2.37	1.87	48.94	86.72	132.23	0.06
						T					12	10.41	-2.84	9.97	1.57	48.91	86.68	132.23	0.132
						T					13	14.17	-4.92	11.99	3.31	48.85	86.61	132.23	0.191
						T					14	11.08	-3.47	6.44	2.47	48.9	86.67	132.23	0.12
						T					15	3.25	0.06	0.28	0.36	48.97	86.76	132.23	0.004
5130	5536	5525	83.82	2.54	248	K	30.05	45.72	0.952	45.21	11	7.2	-2.52	3.25	0.03	48.94	86.72	132.23	0.075
						K	30.05				12	10.41	-9.92	4.98	1.18	48.91	86.68	132.23	0.24
						K	30.05				13	14.17	-11.61	8.8	1.74	48.85	86.61	132.23	0.303
						T					14	11.08	-4.71	6.56	0.95	49.3	86.67	132.23	0.144
						K	-6.81				15	3.25	0.5	0.36	0.17	56.41	86.76	132.23	0.012
5130	4130	5122	83.82	2.54	248	K	-3.99	40.64	0.952	84.25	11	7.81	-4.35	3.26	5.46	60.06	91.84	132.23	0.107
						T					12	23.84	-5.83	8.76	3.6	59.68	91.43	132.23	0.161
						T					13	28.63	-4.54	13.66	2.92	59.49	91.23	132.23	0.173
						K	-6.81				14	14.65	0.19	9.6	5.04	59.94	91.72	132.23	0.074
						K	-6.71				15	2.9	-0.38	0.28	6.3	60.1	91.88	132.23	0.037
5130	4130	5105	83.82	2.54	248	T		35.56	0.952	81.85	11	7.81	-2.19	4.98	0.24	52.43	98.43	132.23	0.074
						T					12	23.84	2.96	1.61	0.65	52.1	97.99	132.23	0.068
						T					13	28.63	5.16	2.01	1.25	51.93	97.77	132.23	0.114
						T					14	14.65	2.78	4.52	0.75	52.33	98.3	132.23	0.083
						T					15	2.9	-1.12	0.18	0.21	52.47	98.48	132.23	0.023

Modified Joint (KT Joint and T Joint)

COMMON JOINT	CHORD JOINT	BRACE JOINT	OD	WT	FY	JOINT TYPE	GAP	OD	WT	RD BRACE AN	OAD CAS	CHORD STS	FA	OPB	IPB	FA	OPB	IPB	unity check
5130	4130	4120	83.82	2.54	248	K	10.84	50.8	0.952	30.83	11	7.02	5.62	2.88	0.96	54.69	82.6	132.23	0.125
						K	21.34				12	22.32	11.29	2.66	1.89	50.59	82.27	132.23	0.246
						K	26.65				13	25.93	10.72	5.07	2.31	48.57	82.15	132.23	0.262
						K	30.05				14	12.71	1.99	4.06	0.38	47.65	82.52	132.23	0.073
						T					15	3.88	-0.04	0.13	1.45	47.74	82.63	132.23	0.008
5130	5536	5525	83.82	2.54	248	K	30.05	45.72	0.952	45.21	11	7.22	-2.73	3.47	0.09	48.94	86.72	132.23	0.081
						K	30.05				12	11.22	-9.35	4.06	1.92	48.9	86.67	132.23	0.222
						K	30.05				13	14.34	-10.7	7.6	2.69	48.85	86.61	132.23	0.277
						K	13.1				14	10.75	-4.16	5.93	1.45	53.96	86.68	132.23	0.121
						K	-3.41				15	3.72	0.44	0.33	0.24	59.07	86.75	132.23	0.01
5130	4130	5122	83.82	2.54	248	K	-3.99	40.64	0.952	84.25	11	7.02	-5.19	3.8	5.32	60.07	91.85	132.23	0.123
						K	-3.99				12	22.32	-3.84	7.44	3	59.73	91.49	132.23	0.118
						K	-3.99				13	25.93	-1.34	12.06	2.22	59.6	91.35	132.23	0.107
						K	-6.81				14	12.71	2.13	8.9	4.69	59.98	91.76	132.23	0.101
						K	-6.81				15	3.88	-0.61	0.39	6.35	58.4	91.88	132.23	0.041
5130	4130	5140	83.82	2.54	248	T		40.64	0.952	84.25	11	7.02	0.42	3.54	0.96	50.47	91.85	132.23	0.033
						T					12	22.32	0.52	7.21	2.72	50.19	91.49	132.23	0.062
						T					13	25.93	0.53	10.9	4.03	50.08	91.35	132.23	0.089
						T					14	12.71	-0.16	7.8	4.17	50.4	91.76	132.23	0.061
						T					15	3.88	-0.37	0.17	2.31	50.5	91.88	132.23	0.019
5130	4130	5105	83.82	2.54	248	T		35.56	0.952	81.85	11	7.02	0.28	4.54	0.1	52.44	98.44	132.23	0.035
						T					12	22.32	-2.22	0.42	0.94	52.14	98.05	132.23	0.048
						T					13	25.93	-3.27	4.67	1.67	52.03	97.9	132.23	0.094
						T					14	12.71	-2.43	5.83	0.91	52.37	98.34	132.23	0.084
						T					15	3.88	-0.55	0	0	52.46	98.47	132.23	0.011

Modified Joint (K Joint and N Joint)

COMMON JOINT	CHORD JOINT	BRACE JOINT	OD	WT	FY	JOINT TYPE	GAP	OD	WT	RD BRACE AN	OAD CAS	CHORD STS	FA	OPB	IPB	FA	OPB	IPB	unity check
5130	4130	4120	83.82	2.54	248	K	30.05	50.8	0.952	30.83	11	7.4	5.5	3.02	0.97	47.72	82.6	132.23	0.139
						K	30.05				12	23.25	10.69	3.37	1.99	47.43	82.24	132.23	0.253
						K	30.05				13	27.64	10.04	6.1	2.49	47.29	82.08	132.23	0.261
						K	30.05				14	14.23	1.72	4.68	0.63	47.63	82.49	132.23	0.072
						K	30.05				15	3.6	-0.04	0.23	1.36	47.74	82.63	132.23	0.008
5130	5536	5535	83.82	2.54	248	T		45.72	0.952	45.21	11	6.32	2.92	2.84	1.41	50.45	86.73	132.23	0.08
						K	-6.81				12	8.82	-4.6	8.73	0.33	60.05	86.7	132.23	0.141
						K	-6.81				13	11.95	-7.9	10.09	1.32	59.42	86.66	132.23	0.207
						K	-6.81				14	9.67	-5.33	5.05	1.18	56.61	86.69	132.23	0.132
						K	-6.81				15	2.79	0.36	0.41	0.31	60.1	86.76	132.23	0.009
5130	5536	5525	83.82	2.54	248	K	30.05	45.72	0.952	45.21	11	6.32	-5.03	3.34	1.21	48.95	86.73	132.23	0.128
						K	30.05				12	8.82	-11.63	5.75	0.23	48.93	86.7	132.23	0.28
						K	30.05				13	11.95	-12.05	9.79	1.28	48.89	86.66	132.23	0.319
						K	30.05				14	9.67	-3.59	7.19	1.09	48.92	86.69	132.23	0.127
						T					15	2.79	0.19	0.39	0.56	48.97	86.76	132.23	0.008
5130	4130	5140	83.82	2.54	248	K	-6.81	40.64	0.952	84.25	11	7.4	-0.44	3.44	1.47	60.06	91.85	132.23	0.032
						K	-6.81				12	23.25	6.22	4.22	2.44	58.11	91.45	132.23	0.139
						K	-6.81				13	27.64	8.45	6.87	3.39	59.53	91.27	132.23	0.193
						K	-6.81				14	14.23	4.16	5.34	3.8	59.95	91.73	132.23	0.111
						K	-6.81				15	3.6	-0.44	0.19	2.58	59.28	91.88	132.23	0.02
5130	4130	5105	83.82	2.54	248	T		35.56	0.952	81.85	11	7.4	-3.74	4.82	0.3	52.44	98.44	132.23	0.103
						T					12	23.25	-3.26	4.06	0.61	52.12	98.01	132.23	0.089
						T					13	27.64	-1.86	1.01	1.09	51.97	97.82	132.23	0.044
						T					14	14.23	0.35	2.72	0.49	52.34	98.31	132.23	0.025
						T					15	3.6	-0.99	0.04	0.09	52.47	98.47	132.23	0.019

Modified Joint (N Joint and N Joint)

COMMON JOINT	CHORD JOINT	BRACE JOINT	OD	WT	FY	JOINT TYPE	GAP	OD	WT	RD BRACE AN	OAD CAS	CHORD STS	FA	OPB	IPB	FA	OPB	IPB	unity check
5130	4130	4120	83.82	2.54	248	K	-3.99	50.8	0.952	30.83	11	7.14	5.92	2.93	1.08	60.07	82.6	132.23	0.122
						K	-3.99				12	21.6	11.46	3.25	1.82	59.04	82.3	132.23	0.221
						K	-3.99				13	25.4	10.77	5.88	2.19	58.94	82.17	132.23	0.23
						K	-3.99				14	12.71	1.87	4.51	0.38	59.98	82.52	132.23	0.066
						T					15	3.68	-0.05	0.23	1.37	47.74	82.63	132.23	0.008
5130	5536	5535	83.82	2.54	248	T		45.72	0.952	45.21	11	7.26	2.79	2.9	1.67	54.41	86.72	132.23	0.074
						K	-6.81				12	10.57	-4.56	8.7	0.85	60.02	86.68	132.23	0.14
						K	-6.81				13	14.27	-7.74	10.02	2.16	59.95	86.61	132.23	0.204
						K	-6.81				14	11.11	-5.17	5.14	1.73	59	86.67	132.23	0.126
						K	-6.81				15	3.7	0.31	0.2	0.39	60.1	86.75	132.23	0.007
5130	4130	5122	83.82	2.54	248	K	-3.99	40.64	0.952	84.25	11	7.14	-7.54	3.96	5.45	59.94	91.85	132.23	0.164
						K	-3.99				12	21.6	-13.56	10.25	2.4	59.75	91.51	132.23	0.299
						K	-3.99				13	25.4	-12.77	15.93	1.43	59.62	91.37	132.23	0.326
						K	-3.99				14	12.71	-2.61	11.27	4.54	59.01	91.76	132.23	0.126
						T					15	3.68	-0.15	0.25	6.58	50.5	91.88	132.23	0.035
5130	4130	5140	83.82	2.54	248	K	-6.81	40.64	0.952	84.25	11	7.14	-1.54	3.48	1.18	60.07	91.85	132.23	0.051
						K	-6.81				12	21.6	6.41	4.27	2.78	57.88	91.51	132.23	0.143
						K	-6.81				13	25.4	9.52	6.91	4.02	58.83	91.37	132.23	0.214
						K	-6.81				14	12.71	5.3	5.42	4.26	59.98	91.76	132.23	0.131
						T					15	3.68	-0.7	0.03	2.53	55.21	91.88	132.23	0.025
5130	4130	5105	83.82	2.54	248	T		35.56	0.952	81.85	11	7.14	-1.69	4.4	0.11	52.44	98.44	132.23	0.061
						T					12	21.6	-3.7	3.38	1.27	52.17	98.08	132.23	0.094
						T					13	25.4	-4.01	0.52	2.06	52.05	97.92	132.23	0.088
						T					14	12.71	-1.91	2.78	1.04	52.37	98.34	132.23	0.055
						T					15	3.68	-0.51	0.23	0	52.46	98.47	132.23	0.011

BOVA1 (JOINT 2130)

Original Joint (KT Joint and T Joint)

COMMON JOINT	CHORD JOINT	BRACE JOINT	OD	WT	FY	JOINT TYPE	GAP	OD	WT	RD BRACE AN	OAD CAS	CHORD STS	FA	OPB	IPB	FA	OPB	IPB	unity check
2130	2131	1140	84.49	2.875	248	K	60.62	31.88	0.97	31.27	11	4.37	-0.72	0.56	0.11	61.11	117.9	132.23	0.015
						K	60.62				12	42.7	1.38	5.63	2.17	59.88	116.3	132.23	0.056
						K	60.62				13	59.27	5.81	4.72	3.63	58.72	114.7	132.23	0.13
						K	60.62				14	31.21	6.72	0.54	2.08	60.46	117.1	132.23	0.122
						K	18.64				15	2.52	0.29	0.01	0.15	68.01	118	132.23	0.005
2130	3130	3140	84.49	2.875	248	K	33.4	34.96	0.652	41.17	11	4.45	1.85	5.6	4.37	70.37	112.1	132.23	0.064
						T					12	38.81	-6.49	8.65	3.58	66.15	110.8	132.23	0.151
						K	43.07				13	49.75	-12.37	8.06	6.98	63.57	109.9	132.23	0.252
						K	50.29				14	22.41	-9.82	1.73	5.43	63.24	111.6	132.23	0.183
						T					15	2.73	0.03	0.09	0.2	86.15	112.1	132.23	0.002
2130	2131	2122	84.49	2.875	248	T		31.79	0.97	84.25	11	4.37	-2.38	0.42	4.64	61.17	118.1	132.23	0.061
						T					12	42.7	-1.75	8.5	0.39	59.93	116.5	132.23	0.076
						T					13	59.27	-0.47	12.04	0.36	58.77	114.9	132.23	0.075
						T					14	31.21	0.79	7.85	3.96	60.51	117.3	132.23	0.06
						T					15	2.52	-0.3	0.02	4.46	61.18	118.2	132.23	0.026
2130	2131	2140	84.49	2.875	248	K	10.03	31.79	0.97	84.25	11	4.37	-0.85	1.28	1.04	88.76	118.1	132.23	0.018
						K	10.03				12	42.7	2.13	5.56	1.94	86.96	116.5	132.23	0.056
						K	10.03				13	59.27	3.1	7.64	4.01	85.28	114.9	132.23	0.083
						K	10.03				14	31.21	1.73	5.49	3.02	87.81	117.3	132.23	0.053
						K	18.64				15	2.52	-0.22	0.39	0.15	70.47	118.2	132.23	0.005
2130	2131	2105	84.49	2.875	248	T		31.79	0.97	81.85	11	4.37	-0.32	2.79	0.34	61.17	118.1	132.23	0.02
						T					12	42.7	0.3	2.77	2.06	59.93	116.5	132.23	0.023
						T					13	59.27	0.48	1.12	2.92	58.77	114.9	132.23	0.023
						T					14	31.21	0.01	3.88	0.93	60.51	117.3	132.23	0.022
						T					15	2.52	-0.23	0.34	0.51	61.18	118.2	132.23	0.007

Modified Joint (K Joint and T Joint)

2130	2131	1140	84.49	2.875	248	K	60.62	31.88	0.97	31.27	11	4.3	-0.85	0.64	0.04	61.11	118	132.23	0.017
						K	60.62				12	42.24	1.75	5.81	2.27	59.9	116.3	132.23	0.063
						K	60.62				13	58.92	6.35	5	3.78	58.75	114.8	132.23	0.141
						K	60.62				14	31.16	7.01	0.75	2.16	60.46	117.1	132.23	0.127
						T					15	2.54	0.26	0.02	0.16	61.12	118	132.23	0.005
2130	3130	3140	84.49	2.875	248	T		34.96	0.652	41.17	11	4.32	1.7	5.53	4.43	59.36	112.1	132.23	0.067
						T					12	38.39	-6.08	8.87	3.73	58.39	110.8	132.23	0.158
						T					13	49.43	-11.81	8.37	7.22	57.75	109.9	132.23	0.264
						K	60.62				14	22.31	-9.53	1.95	5.57	59.04	111.7	132.23	0.19
						K	60.62				15	2.73	-0.01	0.1	0.21	59.37	112.1	132.23	0.001
2130	2131	2122	84.49	2.875	248	T		31.79	0.97	84.25	11	4.3	-1.87	0.34	4.68	61.17	118.1	132.23	0.053
						T					12	42.24	-2.44	8.02	0.49	59.96	116.5	132.23	0.085
						T					13	58.92	-1.64	11.39	0.44	58.8	114.9	132.23	0.091
						T					14	31.16	0.06	7.33	3.98	60.52	117.3	132.23	0.045
						T					15	2.54	-0.2	0.05	4.45	61.18	118.2	132.23	0.025
2130	2131	2105	84.49	2.875	248	T		31.79	0.97	81.85	11	4.3	-0.91	2.5	0.33	61.17	118.1	132.23	0.028
						T					12	42.24	1.77	2.8	2.07	59.96	116.5	132.23	0.048
						T					13	58.92	2.62	0.91	3	58.8	114.9	132.23	0.06
						T					14	31.16	1.23	3.92	1.01	60.52	117.3	132.23	0.042
						T					15	2.54	-0.38	0.51	0.51	61.18	118.2	132.23	0.01

Modified Joint (N Joint and T Joint)

2130	2131	2122	84.49	2.875	248	T		31.79	0.97	84.25	11	3.72	-2.13	0.6	4.59	61.17	118.1	132.23	0.026
						T					12	42.13	-1.81	8.35	0.83	59.96	116.5	132.23	0.036
						T					13	59.48	-1.87	13.72	1.02	58.76	114.9	132.23	0.093
						T					14	32.17	-1.12	10.39	4.43	60.47	117.2	132.23	0.088
						T					15	2.5	-0.38	0.13	4.48	61.18	118.2	132.23	0.003
2130	2131	2140	84.49	2.875	248	K	10.03	31.79	0.97	84.25	11	3.72	-1.37	1.16	0.22	88.76	118.1	132.23	0.123
						K	10.03				12	42.13	3.05	5.74	3.25	87.01	116.5	132.23	0.118
						K	10.03				13	59.48	7.07	6.39	10.2	85.26	114.9	132.23	0.107
						K	10.03				14	32.17	6.37	3.54	10.4	87.75	117.2	132.23	0.101
						T					15	2.5	-0.02	0.31	0.5	61.18	118.2	132.23	0.041
2130	2131	2105	84.49	2.875	248	T		31.79	0.97	81.85	11	3.72	-0.72	2.73	0.07	61.17	118.1	132.23	0.033
						T					12	42.13	1.18	2.1	2.48	59.96	116.5	132.23	0.062
						T					13	59.48	3.8	0.46	5.88	58.76	114.9	132.23	0.089
						T					14	32.17	3.75	2.22	4.69	60.47	117.2	132.23	0.061
						T					15	2.5	-0.07	0.26	0.33	61.18	118.2	132.23	0.019

Modified Joint (N Joint and T Joint)

COMMON JOINT	CHORD JOINT	BRACE JOINT	OD	WT	FY	JOINT TYPE	GAP	OD	WT	RD BRACE AN	OAD CAS	CHORD STS	FA	OPB	IPB	FA	OPB	IPB	unity check
2130	2131	1140	83.82	2.54	248	K	30.05	50.8	0.952	30.83	11	7.4	5.5	3.02	0.97	47.72	82.6	132.23	0.139
						K	30.05				12	23.25	10.69	3.37	1.99	47.43	82.24	132.23	0.253
						K	30.05				13	27.64	10.04	6.1	2.49	47.29	82.08	132.23	0.261
						K	30.05				14	14.23	1.72	4.68	0.63	47.63	82.49	132.23	0.072
						K	30.05				15	3.6	-0.04	0.23	1.36	47.74	82.63	132.23	0.008
2130	3130	3140	83.82	2.54	248	T		45.72	0.952	45.21	11	6.32	2.92	2.84	1.41	50.45	86.73	132.23	0.08
						K	-6.81				12	8.82	-4.6	8.73	0.33	60.05	86.7	132.23	0.141
						K	-6.81				13	11.95	-7.9	10.09	1.32	59.42	86.66	132.23	0.207
						K	-6.81				14	9.67	-5.33	5.05	1.18	56.61	86.69	132.23	0.132
						K	-6.81				15	2.79	0.36	0.41	0.31	60.1	86.76	132.23	0.009
2130	2131	2122	83.82	2.54	248	K	30.05	45.72	0.952	45.21	11	6.32	-5.03	3.34	1.21	48.95	86.73	132.23	0.128
						K	30.05				12	8.82	-11.63	5.75	0.23	48.93	86.7	132.23	0.28
						K	30.05				13	11.95	-12.05	9.79	1.28	48.89	86.66	132.23	0.319
						K	30.05				14	9.67	-3.59	7.19	1.09	48.92	86.69	132.23	0.127
						T					15	2.79	0.19	0.39	0.56	48.97	86.76	132.23	0.008
2130	2131	2105	83.82	2.54	248	K	-6.81	40.64	0.952	84.25	11	7.4	-0.44	3.44	1.47	60.06	91.85	132.23	0.032
						K	-6.81				12	23.25	6.22	4.22	2.44	58.11	91.45	132.23	0.139
						K	-6.81				13	27.64	8.45	6.87	3.39	59.53	91.27	132.23	0.193
						K	-6.81				14	14.23	4.16	5.34	3.8	59.95	91.73	132.23	0.111
						K	-6.81				15	3.6	-0.44	0.19	2.58	59.28	91.88	132.23	0.02
5130	4130	5105	83.82	2.54	248	T		35.56	0.952	81.85	11	7.4	-3.74	4.82	0.3	52.44	98.44	132.23	0.103
						T					12	23.25	-3.26	4.06	0.61	52.12	98.01	132.23	0.089
						T					13	27.64	-1.86	1.01	1.09	51.97	97.82	132.23	0.044
						T					14	14.23	0.35	2.72	0.49	52.34	98.31	132.23	0.025
						T					15	3.6	-0.99	0.04	0.09	52.47	98.47	132.23	0.019

Modified Joint (T Joint and T Joint)

COMMON JOINT	CHORD JOINT	BRACE JOINT	OD	WT	FY	JOINT TYPE	GAP	OD	WT	RD BRACE AN	OAD CAS	CHORD STS	FA	OPB	IPB	FA	OPB	IPB	unity check
5130	4130	4120	83.82	2.54	248	K	-3.99	50.8	0.952	30.83	11	7.14	5.92	2.93	1.08	60.07	82.6	132.23	0.122
						K	-3.99				12	21.6	11.46	3.25	1.82	59.04	82.3	132.23	0.221
						K	-3.99				13	25.4	10.77	5.88	2.19	58.94	82.17	132.23	0.23
						K	-3.99				14	12.71	1.87	4.51	0.38	59.98	82.52	132.23	0.066
						T					15	3.68	-0.05	0.23	1.37	47.74	82.63	132.23	0.008
5130	5536	5535	83.82	2.54	248	T		45.72	0.952	45.21	11	7.26	2.79	2.9	1.67	54.41	86.72	132.23	0.074
						K	-6.81				12	10.57	-4.56	8.7	0.85	60.02	86.68	132.23	0.14
						K	-6.81				13	14.27	-7.74	10.02	2.16	59.95	86.61	132.23	0.204
						K	-6.81				14	11.11	-5.17	5.14	1.73	59	86.67	132.23	0.126
						K	-6.81				15	3.7	0.31	0.2	0.39	60.1	86.75	132.23	0.007
5130	4130	5122	83.82	2.54	248	K	-3.99	40.64	0.952	84.25	11	7.14	-7.54	3.96	5.45	59.94	91.85	132.23	0.164
						K	-3.99				12	21.6	-13.56	10.25	2.4	59.75	91.51	132.23	0.299
						K	-3.99				13	25.4	-12.77	15.93	1.43	59.62	91.37	132.23	0.326
						K	-3.99				14	12.71	-2.61	11.27	4.54	59.01	91.76	132.23	0.126
						T					15	3.68	-0.15	0.25	6.58	50.5	91.88	132.23	0.035
5130	4130	5140	83.82	2.54	248	K	-6.81	40.64	0.952	84.25	11	7.14	-1.54	3.48	1.18	60.07	91.85	132.23	0.051
						K	-6.81				12	21.6	6.41	4.27	2.78	57.88	91.51	132.23	0.143
						K	-6.81				13	25.4	9.52	6.91	4.02	58.83	91.37	132.23	0.214
						K	-6.81				14	12.71	5.3	5.42	4.26	59.98	91.76	132.23	0.131
						T					15	3.68	-0.7	0.03	2.53	55.21	91.88	132.23	0.025
5130	4130	5105	83.82	2.54	248	T		35.56	0.952	81.85	11	7.14	-1.69	4.4	0.11	52.44	98.44	132.23	0.061
						T					12	21.6	-3.7	3.38	1.27	52.17	98.08	132.23	0.094
						T					13	25.4	-4.01	0.52	2.06	52.05	97.92	132.23	0.088
						T					14	12.71	-1.91	2.78	1.04	52.37	98.34	132.23	0.055
						T					15	3.68	-0.51	0.23	0	52.46	98.47	132.23	0.011

APPENDIX C.2: Load Combinations BNVA Platform

BNVA (JOINT 6110)

Original Joint (KT Joint and T Joint)

MMON JO	HORD JOI	RACE JOIN	OD	WT	FY	OINT TYPI	GAP	OD	WT	D BRACE A	OAD CAS	HORD ST	FA	OPB	IPB	FA	OPB	IPB	unity check
6120	5120	5110	67.31	1.905	248	K	-0.73	45.72	0.952	39.38	9	23.65	-10.84	1.05	4.24	56.01	74.59	131.94	0.216
						K	-0.73				10	27.2	-12.46	1.21	4.88	56.01	74.59	131.94	0.248
						K	-0.73				11	28.36	-13	1.26	5.05	56.01	74.59	131.94	0.259
						K	-0.73				12	30.69	-14.08	1.37	5.4	56.01	74.59	131.94	0.28
						T					13	2.28	-0.06	0.03	0.77	43.39	74.58	131.94	0.005
6120	7120	7110	67.3	1 1.90	5 248.0	K	-3.35	50.8	0 0.952	51.52	9	9.84	13.59	2.17	2.71	53.55	75.14	131.94	0.276
						K	-3.35				10	11.32	15.63	2.5	3.11	53.53	75.12	131.94	0.318
						K	-3.34				11	11.77	16.31	2.61	3.4	53.51	75.11	131.94	0.332
						K	-3.33				12	12.66	17.68	2.83	3.96	53.48	75.09	131.94	0.361
						T					13	1.72	-0.06	0.03	2.98	42.47	75.21	131.94	0.016
6120	5120	6110	67.31	1.905	248	K	-20.76	35.56	0.952	85.28	9	23.65	-2.1	7.81	3.57	56.01	82.09	131.94	0.101
						K	-20.76				10	27.2	-2.42	8.98	4.11	56.01	82.09	131.94	0.116
						K	-20.76				11	28.36	-2.52	9.36	4.35	56.01	82.09	131.94	0.121
						K	-20.76				12	30.69	-2.71	10.13	4.85	56.01	82.09	131.94	0.131
						T					13	2.28	-0.15	0.11	1.4	46.01	82.09	131.94	0.01
6120	7120	6110	67.31	1.905	248	K	-20.77	35.56	0.952	94.71	9	9.84	-2.1	7.81	3.57	55.94	82.02	131.94	0.101
						K	-20.77				10	11.32	-2.42	8.98	4.11	55.91	81.99	131.94	0.116
						K	-20.77				11	11.77	-2.52	9.36	4.35	55.91	81.99	131.94	0.121
						K	-20.77				12	12.66	-2.71	10.13	4.85	55.89	81.97	131.94	0.131
						T					13	1.72	-0.15	0.11	1.4	46.01	82.09	131.94	0.01
6120	5120	6130	67.31	1.905	248	T		35.56	0.952	87.64	9	23.65	-2.5	5.93	1.96	46.01	82.09	131.94	0.101
						T					10	27.2	-2.88	6.82	2.26	46.01	82.09	131.94	0.117
						T					11	28.36	-3.01	7.12	2.28	46.01	82.09	131.94	0.122
						T					12	30.69	-3.26	7.71	2.31	46.01	82.09	131.94	0.132
						T					13	2.28	0.07	0.01	1.63	46.01	82.09	131.94	0.009
6120	7120	6130	67.31	1.905	248	T		35.56	0.952	92.35	9	9.84	-2.5	5.93	1.97	45.95	82.02	131.94	0.101
						T					10	11.32	-2.88	6.82	2.26	45.93	81.99	131.94	0.117
						T					11	11.77	-3.01	7.12	2.28	45.92	81.99	131.94	0.122
						T					12	12.66	-3.26	7.71	2.31	45.91	81.97	131.94	0.132
						T					13	1.72	0.07	0.01	1.63	46.01	82.09	131.94	0.009

Modified Joint (K Joint and T Joint)

MMON JO	HORD JOI	RACE JOIN	OD	WT	FY	OINT TYP	GAP	OD	WT	D BRACE	OAD CAS	HORD ST	FA	OPB	IPB	FA	OPB	IPB	unity check
6120	5120	5110	67.31	1.905	248	K	-0.73	45.72	0.952	39.38	9	24.14	-11.59	0.28	4.9	56.01	74.59	131.94	0.231
						K	-0.73				10	27.77	-13.33	0.32	5.64	56.01	74.59	131.94	0.265
						K	-0.73				11	28.95	-13.9	0.34	5.84	56.01	74.59	131.94	0.277
						K	-0.73				12	31.31	-15.05	0.37	6.24	56.01	74.59	131.94	0.299
						T					13	2.12	-0.12	0.05	0.86	43.39	74.58	131.94	0.007
6120	7120	7110	67.31	1.905	248	K	-0.73	50.8	0.952	51.52	9	10.73	12.86	3.16	3.6	53.35	75.13	131.94	0.273
						K	-0.73				10	12.34	14.79	3.64	4.14	53.32	75.1	131.94	0.314
						K	-0.73				11	12.83	15.44	3.8	4.46	53.31	75.09	131.94	0.328
						K	-0.73				12	13.81	16.73	4.11	5.12	53.27	75.07	131.94	0.357
						T					13	1.63	-0.11	0.01	2.98	42.47	75.21	131.94	0.017
6120	5120	6130	67.31	1.905	248	T		35.56	0.952	87.64	9	24.14	-2.45	5.45	1.9	46.01	82.09	131.94	0.096
						T					10	27.77	-2.81	6.27	2.18	46.01	82.09	131.94	0.111
						T					11	28.95	-2.94	6.54	2.19	46.01	82.09	131.94	0.116
						T					12	31.31	-3.19	7.09	2.22	46.01	82.09	131.94	0.125
						T					13	2.12	0.07	0.02	1.67	46.01	82.09	131.94	0.009
6120	7120	6130	67.31	1.905	248	T		35.56	0.952	92.35	9	10.73	-2.45	5.45	1.9	45.94	82	131.94	0.097
						T					10	12.34	-2.81	6.27	2.18	45.91	81.97	131.94	0.111
						T					11	12.83	-2.94	6.54	2.19	45.91	81.97	131.94	0.116
						T					12	13.81	-3.19	7.09	2.22	45.89	81.94	131.94	0.126
						T					13	1.63	0.07	0.02	1.67	46.01	82.09	131.94	0.009

Modified Joint (N Joint and T Joint)

MMON JO	HORD JOI	RACE JOIN	OD	WT	FY	OINT TYPI	GAP	OD	WT	D BRACE	OAD CAS	HORD ST	FA	OPB	IPB	FA	OPB	IPB	unity check
6120	7120	7110	67.31	1.905	248	T		50.8	0.952	51.52	9	53.72	17.97	7.23	14.18	47.17	73.15	131.94	0.474
						T					10	61.78	20.66	8.31	16.3	46.55	72.49	131.94	0.552
						T					11	64.4	21.56	8.67	17.16	46.33	72.25	131.31	0.579
						T					12	69.64	23.36	9.37	18.87	45.85	71.75	129.26	0.635
						T					13	1.87	-0.01	0.14	2.91	42.47	75.2	131.94	0.014
6120	5120	6110	67.31	1.905	248	K	-20.76	35.56	0.952	85.28	9	75.79	-12.64	0.36	31.29	51.66	77.63	131.94	0.397
						K	-20.76				10	87.16	-14.54	0.41	35.98	50.25	76.19	131.28	0.466
						K	-20.76				11	90.98	-15.16	0.43	37.6	49.74	75.66	129.14	0.493
						K	-20.76				12	98.62	-16.4	0.47	40.85	48.64	74.53	124.57	0.55
						T					13	1.49	-0.26	0.03	1.17	46.01	82.09	131.94	0.011
6120	7120	6110	67.31	1.905	248	K	-20.77	35.56	0.952	94.71	9	53.72	-12.64	0.36	31.29	53.82	79.85	131.94	0.387
						K	-20.77				10	61.78	-14.54	0.41	35.98	53.12	79.12	131.94	0.45
						K	-20.77				11	64.4	-15.16	0.43	37.6	52.87	78.87	131.94	0.471
						K	-20.77				12	69.64	-16.4	0.47	40.85	52.33	78.32	131.94	0.514
						T					13	1.87	-0.26	0.03	1.17	46.01	82.09	131.94	0.011
6120	5120	6130	67.31	1.905	248	T		35.56	0.952	87.64	9	75.79	-7.06	16.33	1.96	42.43	79.85	131.94	0.302
						T					10	87.16	-8.11	18.78	2.26	41.28	79.12	131.94	0.356
						T					11	90.98	-8.47	19.6	2.27	40.86	78.87	131.94	0.374
						T					12	98.62	-9.17	21.22	2.3	39.95	78.32	131.94	0.414
						T					13	1.49	0.01	0.1	1.68	46.01	82.09	131.94	0.008
6120	7120	6130	67.3	1 1.90	5 248.0	T		35.5	6 0.952	92.35	9	53.72	-7.06	16.33	1.96	44.21	79.85	131.94	0.291
						T					10	61.78	-8.11	18.78	2.26	43.63	79.12	131.94	0.339
						T					11	64.4	-8.47	19.59	2.27	43.43	78.87	131.94	0.355
						T					12	69.64	-9.17	21.22	2.3	42.99	78.32	131.94	0.388
						T					13	1.87	0.01	0.1	1.68	46.01	82.09	131.94	0.008

Modified Joint (N Joint and T Joint)

MMON JO	HORD JOI	RACE JOIN	OD	WT	FY	OINT TYP	GAP	OD	WT	D BRACE	OAD CAS	HORD ST	FA	OPB	IPB	FA	OPB	IPB	unity check
6120	5120	5110	67.31	1.905	248	K	-15.65	45.72	0.952	39.38	9	63.94	-16.64	9.89	8.71	47.39	71.7	131.94	0.449
						K	-15.65				10	73.53	-19.14	11.37	10.02	46.49	70.77	130.38	0.526
						K	-15.65				11	76.64	-19.97	11.86	10.5	46.18	70.44	128.99	0.552
						K	-15.65				12	82.88	-21.63	12.84	11.46	45.51	69.73	126.03	0.607
						T					13	1.7	-0.06	0.07	0.95	43.39	74.58	131.94	0.006
6120	5120	6110	67.31	1.905	248	K	-15.65	35.56	0.952	85.28	9	63.94	11.56	21.22	41.3	52.91	78.91	131.94	0.489
						K	-15.65				10	73.53	13.29	24.4	47.5	51.91	77.89	131.94	0.573
						K	-15.65				11	76.64	13.87	25.45	49.65	51.56	77.53	131.94	0.602
						K	-15.65				12	82.88	15.04	27.56	53.94	50.8	76.75	131.94	0.662
						T					13	1.7	-0.13	0.15	1.66	46.01	82.09	131.94	0.011
6120	7120	6110	67.31	1.905	248	K	-15.65	35.56	0.952	94.71	9	80.83	11.56	21.22	41.31	51.06	77.01	131.94	0.5
						K	-15.65				10	92.95	13.29	24.4	47.5	49.46	75.37	128	0.597
						K	-15.65				11	96.97	13.87	25.45	49.65	48.88	74.78	125.59	0.633
						K	-15.65				12	105.02	15.04	27.56	53.95	47.65	73.52	120.47	0.713
						T					13	1.23	-0.13	0.15	1.66	46.01	82.09	131.94	0.011
6120	5120	6130	67.31	1.905	248	T		35.56	0.952	87.64	9	63.94	4.11	9.82	1.37	43.46	78.91	131.94	0.174
						T					10	73.53	4.72	11.29	1.57	42.64	77.89	131.94	0.204
						T					11	76.64	4.92	11.78	1.55	42.35	77.53	131.94	0.214
						T					12	82.88	5.32	12.75	1.5	41.73	76.75	131.94	0.234
						T					13	1.7	0.09	0.06	1.83	46.01	82.09	131.94	0.011
6120	7120	6130	67.31	1.905	248	T		35.56	0.952	92.35	9	80.83	4.11	9.82	1.36	41.94	77.01	131.94	0.18
						T					10	92.95	4.72	11.29	1.57	40.63	75.37	128	0.212
						T					11	96.97	4.92	11.78	1.55	40.15	74.78	125.59	0.224
						T					12	105.02	5.32	12.75	1.5	39.14	73.52	120.47	0.247
						T					13	1.23	0.09	0.06	1.83	46.01	82.09	131.94	0.011

Modified Joint (T Joint and T Joint)

MMON JO	HORD JOI	RACE JOI	OD	WT	FY	OINT TYP	GAP	OD	WT	D BRACE	OAD CAS	HORD ST	FA	OPB	IPB	FA	OPB	IPB	unity check
6120	5120	6110	67.31	1.905	248	T		35.56	0.952	85.28	9	16.3	0.46	12.69	126.16	46.01	82.09	131.94	0.85
						T					10	18.74	0.53	14.6	145.09	46.01	82.09	131.94	100.012
						T					11	19.52	0.57	15.23	151.45	46.01	82.09	131.94	100.012
						T					12	21.09	0.63	16.49	164.19	46.01	82.09	131.94	100.014
						T					13	1.16	-0.21	0.09	1.23	46.01	82.09	131.94	0.01
6120	7120	6110	67.31	1.905	248	T		35.56	0.952	94.71	9	35.85	0.46	12.69	126.16	45.21	81.09	131.94	0.851
						T					10	41.23	0.53	14.6	145.09	44.95	80.77	131.94	100.012
						T					11	42.99	0.57	15.23	151.45	44.86	80.66	131.94	100.013
						T					12	46.54	0.63	16.49	164.19	44.66	80.41	131.94	100.014
						T					13	1.16	-0.21	0.09	1.23	46.01	82.09	131.94	0.01
6120	5120	6130	67.31	1.905	248	T		35.56	0.952	87.64	9	16.3	-0.79	1.33	1.5	46.01	82.09	131.94	0.03
						T					10	18.74	-0.91	1.53	1.72	46.01	82.09	131.94	0.034
						T					11	19.52	-0.95	1.59	1.7	46.01	82.09	131.94	0.036
						T					12	21.09	-1.04	1.72	1.66	46.01	82.09	131.94	0.038
						T					13	1.16	0.05	0.03	1.89	46.01	82.09	131.94	0.01
6120	7120	6130	67.31	1.905	248	T		35.56	0.952	92.35	9	35.85	-0.79	1.33	1.5	45.21	82.09	131.94	0.03
						T					10	41.23	-0.91	1.53	1.72	44.95	82.09	131.94	0.035
						T					11	42.99	-0.95	1.59	1.7	44.86	82.09	131.94	0.036
						T					12	46.54	-1.04	1.72	1.66	44.66	82.09	131.94	0.039
						T					13	1.16	0.05	0.03	1.89	46.01	82.09	131.94	0.01

APPENDIX E- Effects of Brace-Chord Angles

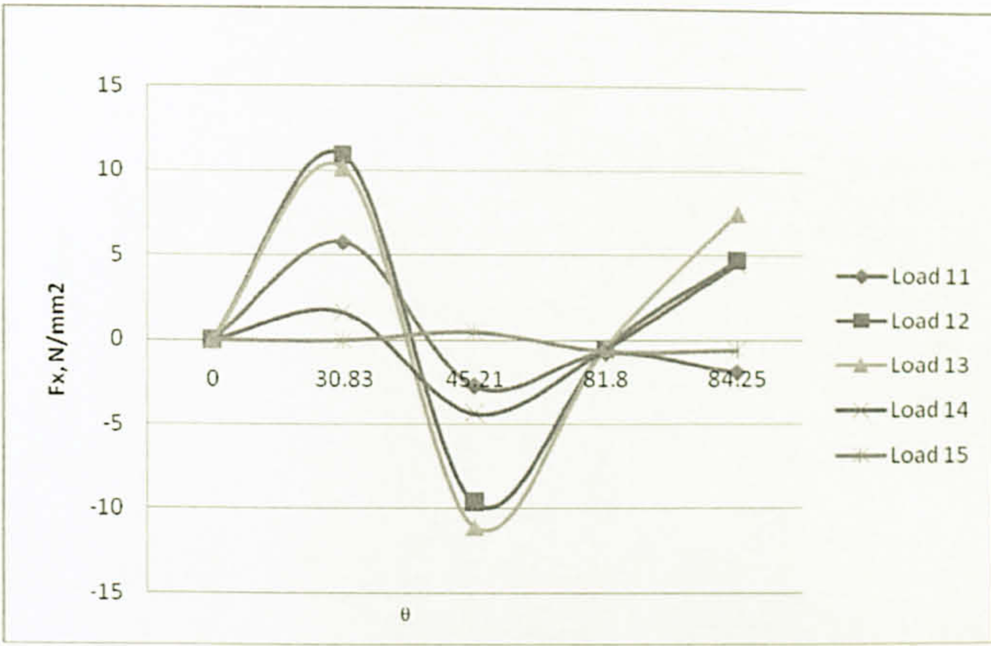
APPENDIX E.1: Platform BOVA-1(Joint 5130)

APPENDIX E.2: Platform BOVA-1(Joint 2130)

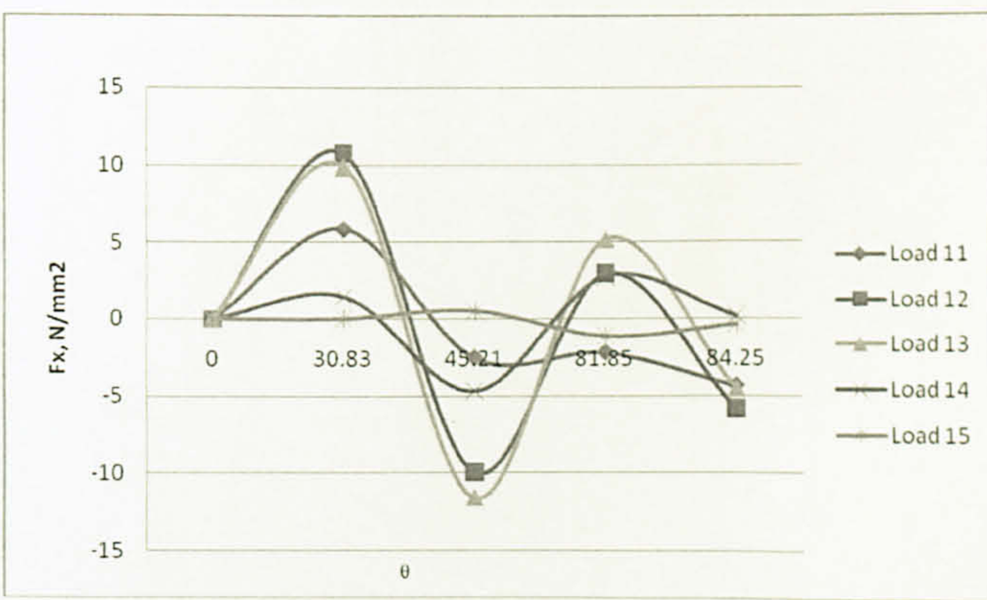
APPENDIX E.3: Platform BNVA (Joint 6110)

APPENDIX E.4: Platform BNVA (Joint 5130)

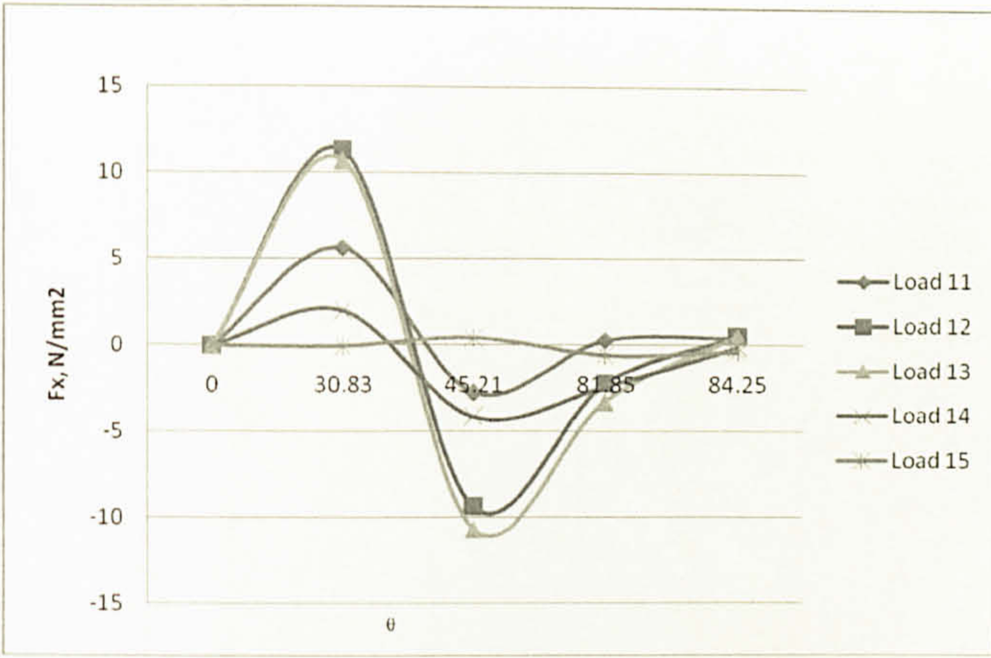
APPENDIX E.1: Platform BOVA-1(Joint 5130)



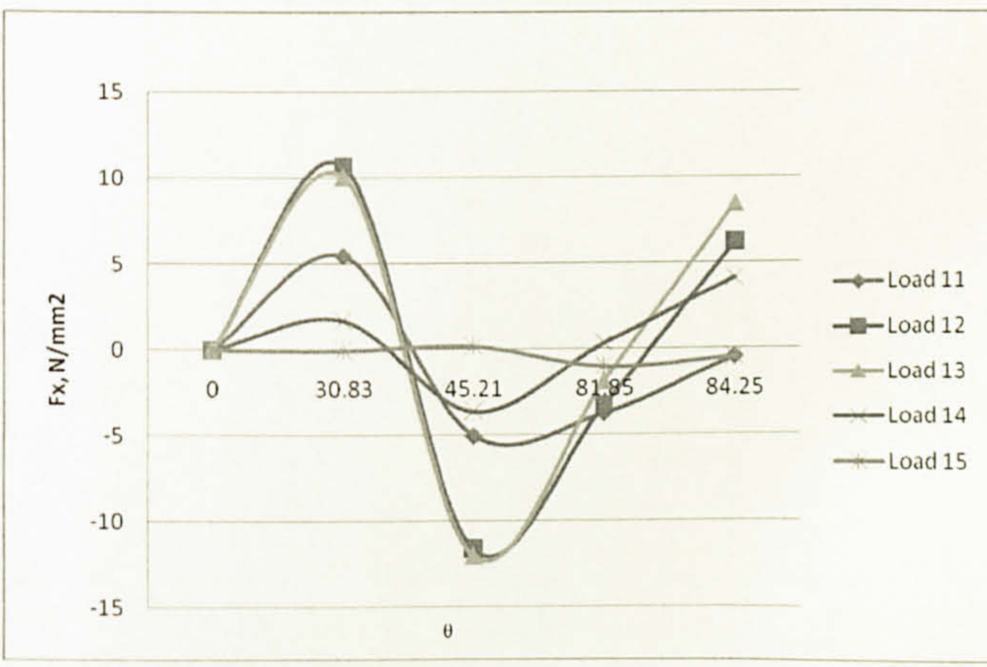
Axial Stress vs Brace Chord Angle for Original Joint 5130



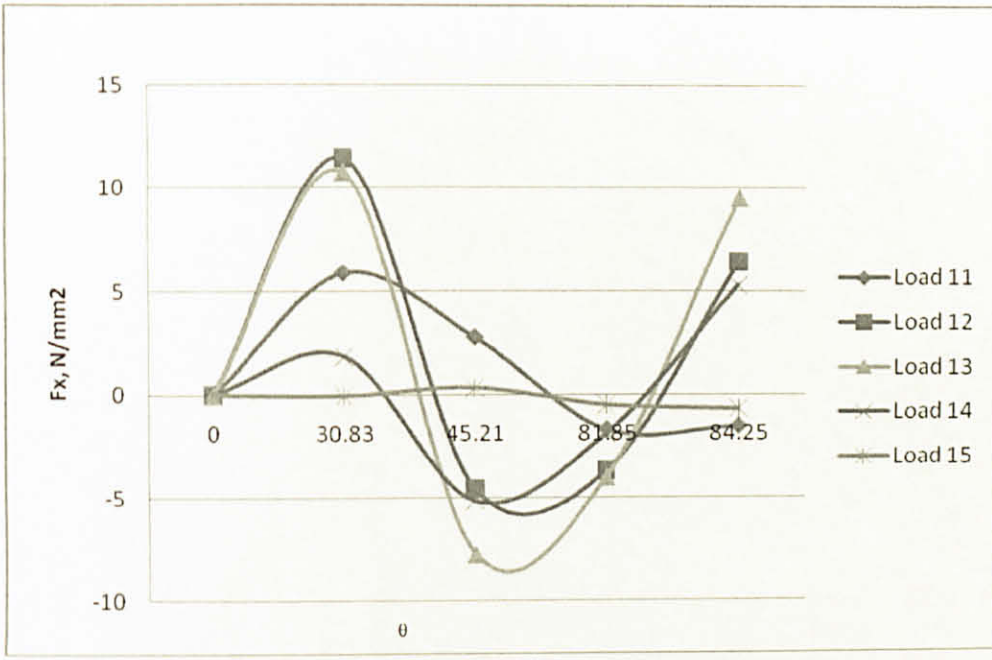
Axial Stress vs Brace Chord Angle for Modified Joint 5130 (N-Y)



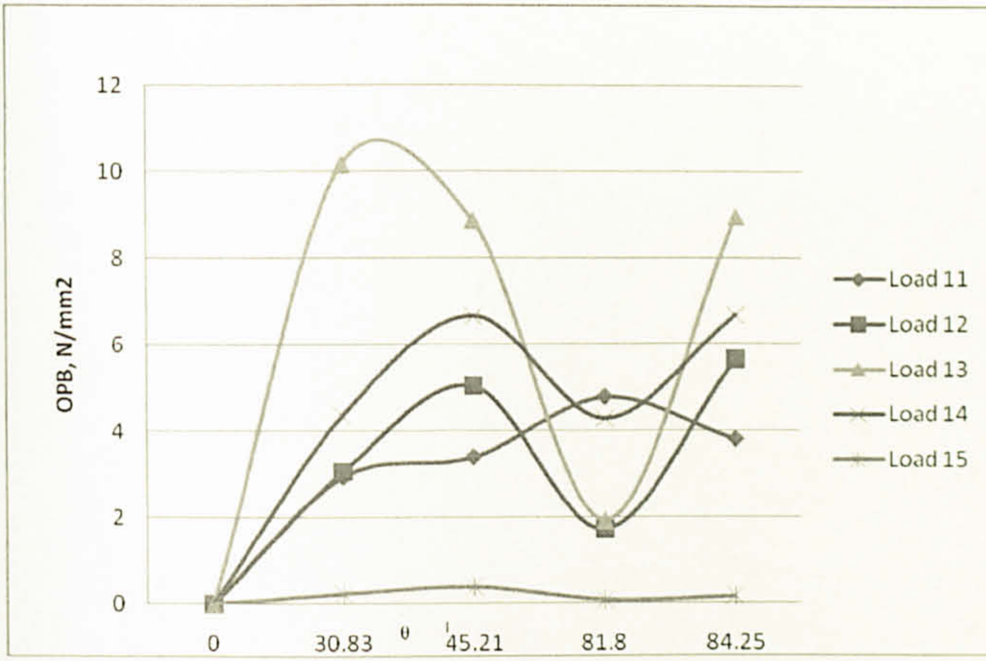
Axial Stress vs Brace Chord Angle for Modified Joint 5130 (N-T)



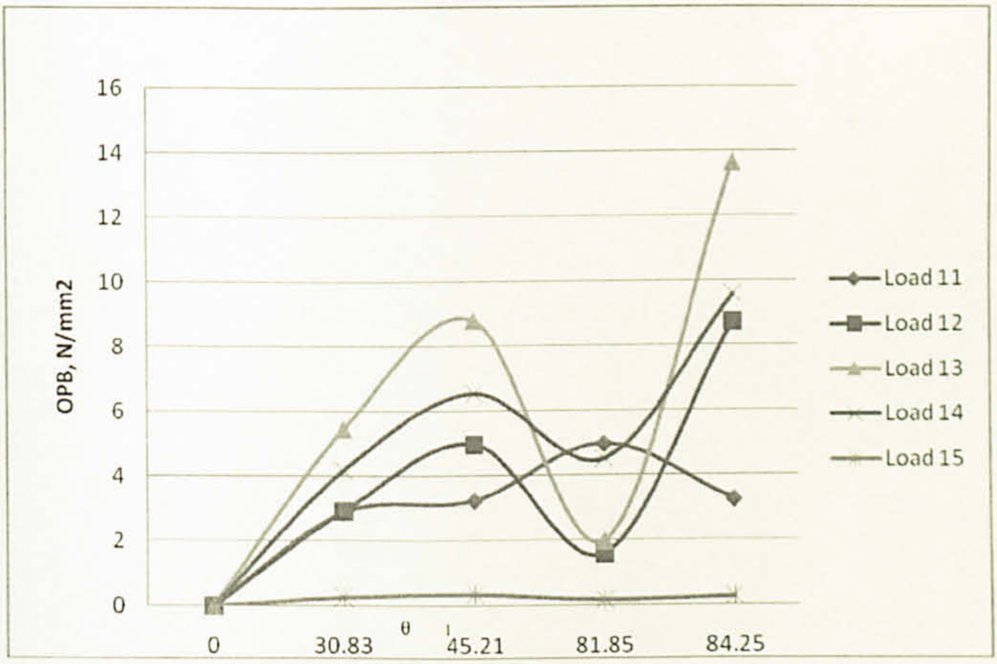
Axial Stress vs Brace Chord Angle for Modified Joint 5130 (KT-K



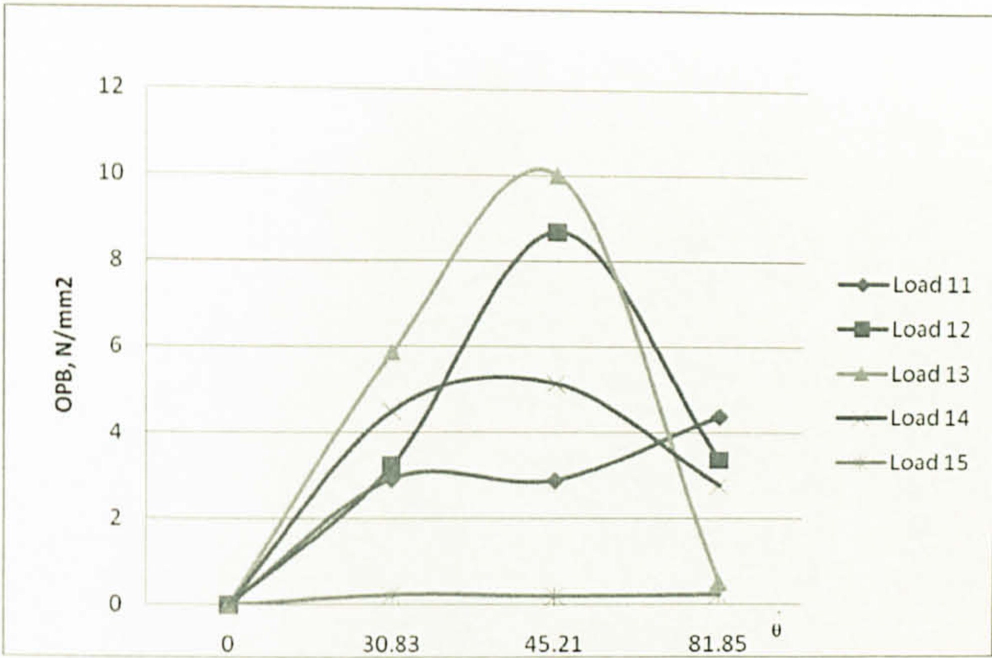
Axial Stress vs Brace Chord Angle for Modified Joint 5130 (KT-N)



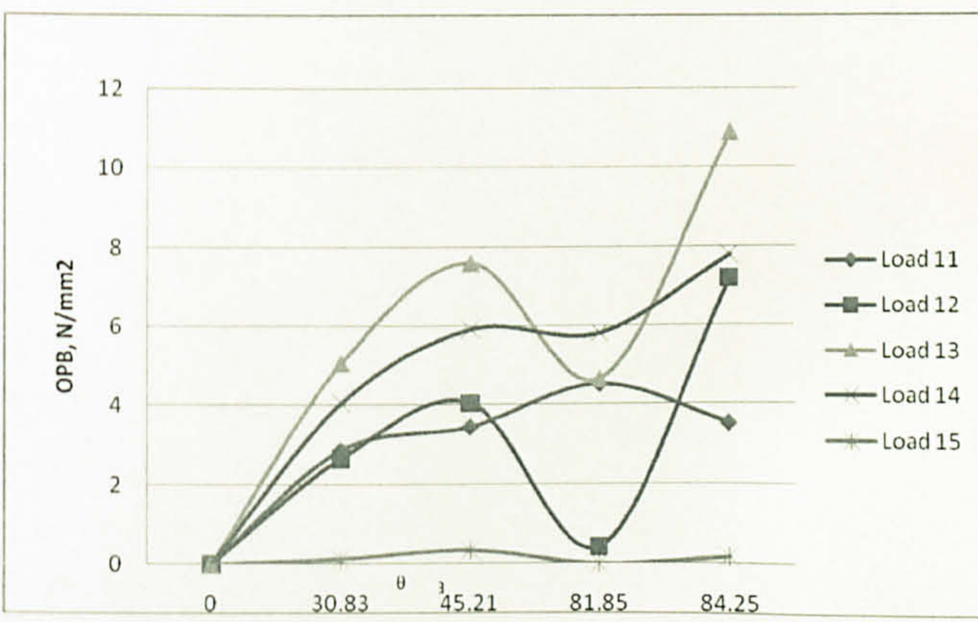
Out of Plane Bending vs Brace Chord Angle for Original Joint 5130



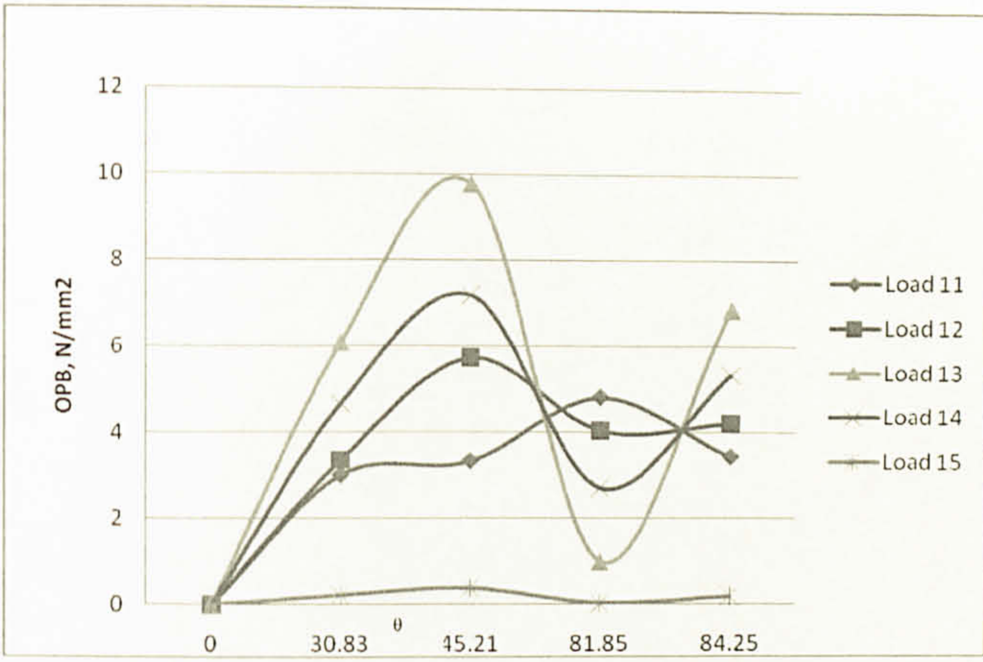
Out of Plane Bending vs Brace Chord Angle for Modified Joint 5130 (N-Y)



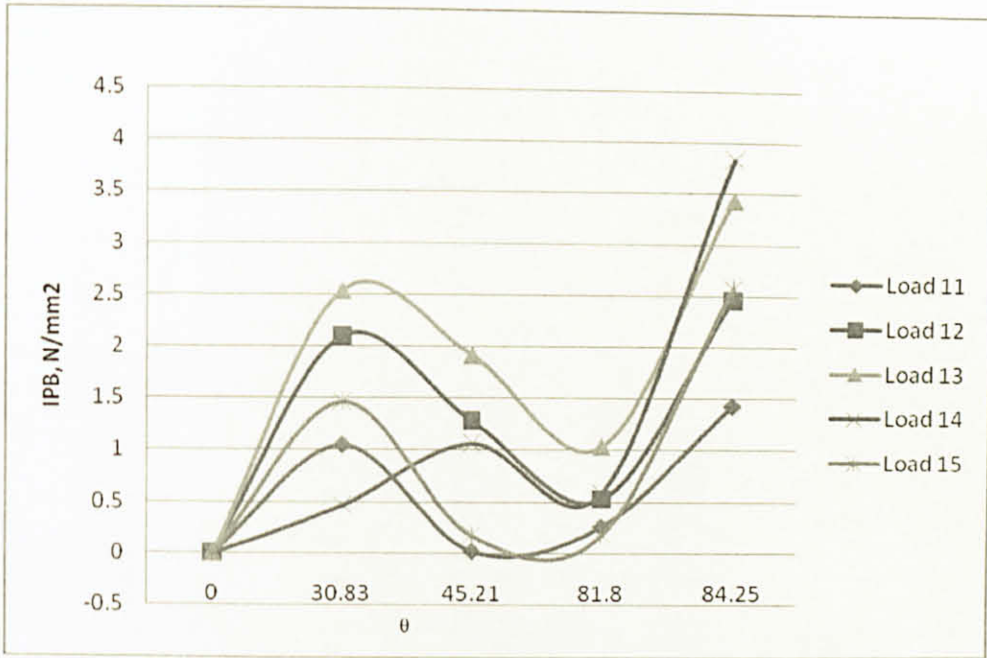
Out of Plane Bending vs Brace Chord Angle for Modified Joint 5130 (N-T)



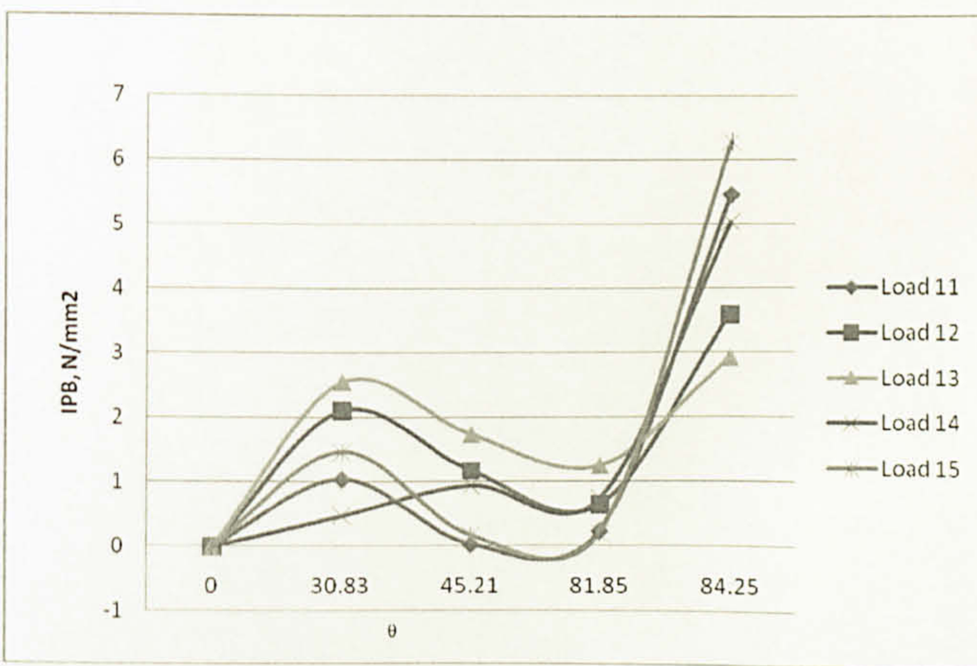
Out of Plane Bending vs Brace Chord Angle for Modified Joint 5130 (KT-K)



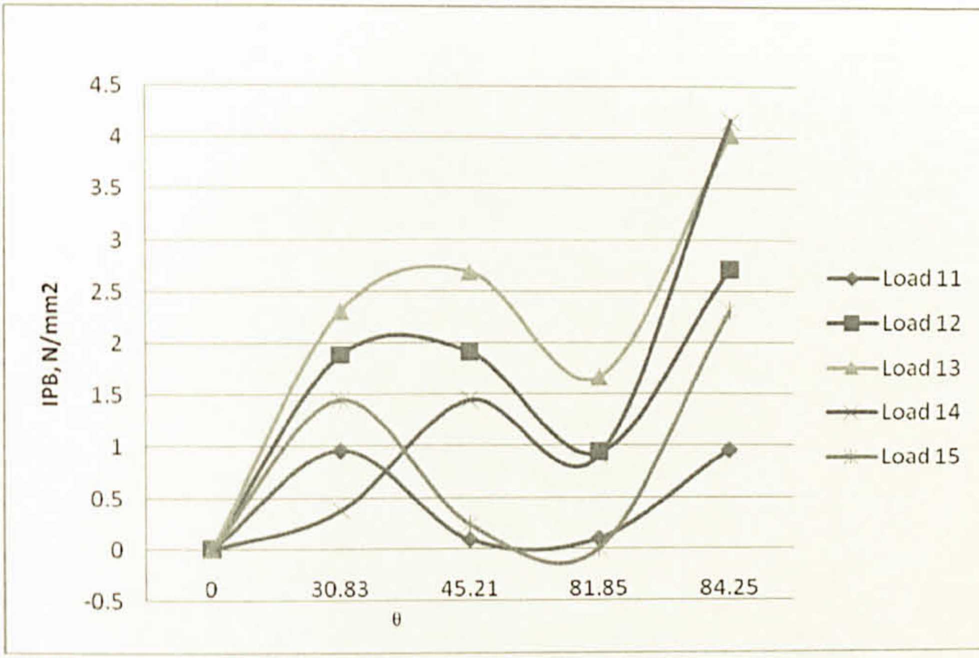
Out of Plane Bending vs Brace Chord Angle for Modified Joint 5130 (KT-N)



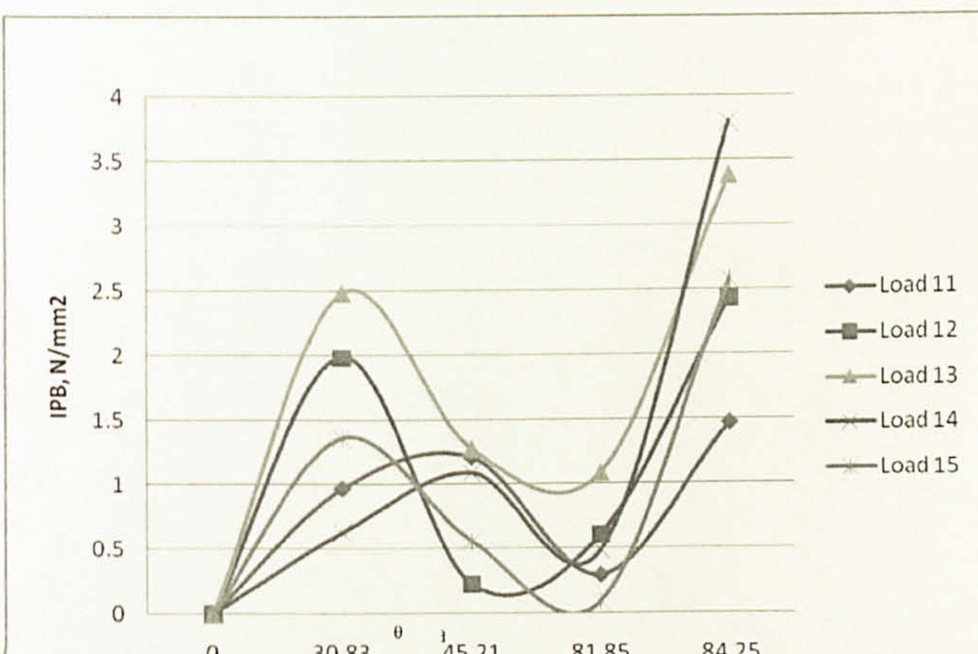
In Plane Bending vs Brace Chord Angle for Original Joint 5130



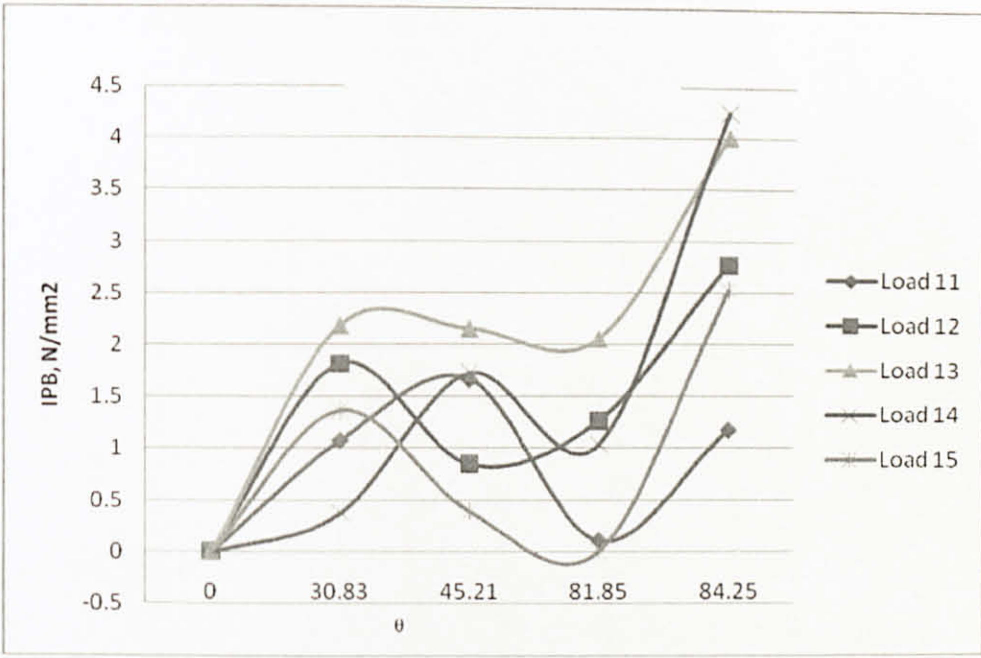
In Plane Bending vs Brace Chord Angle for Modified Joint 5130 (N-Y)



In Plane Bending vs Brace Chord Angle for Modified Joint 5130 (N-T)

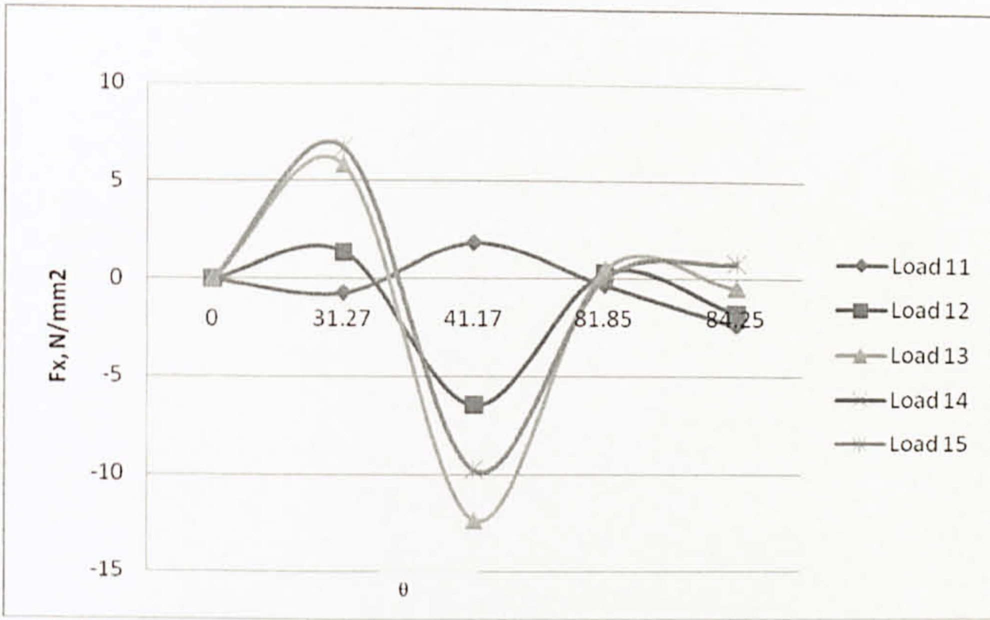


In Plane Bending vs Brace Chord Angle for Modified Joint 5130 (KT-K)

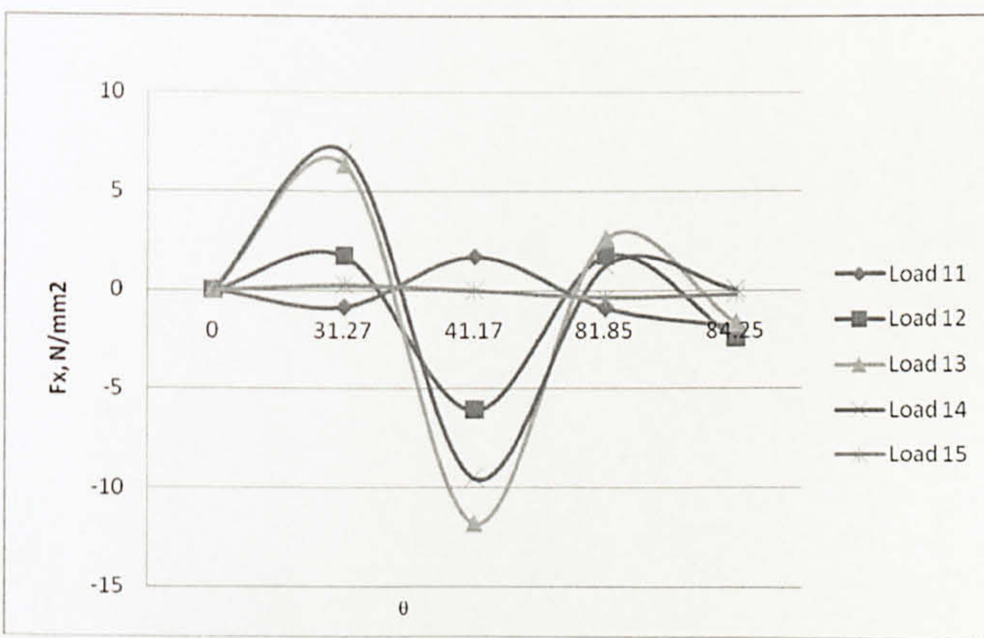


In Plane Bending vs Brace Chord Angle for Modified Joint 5130 (KT-N)

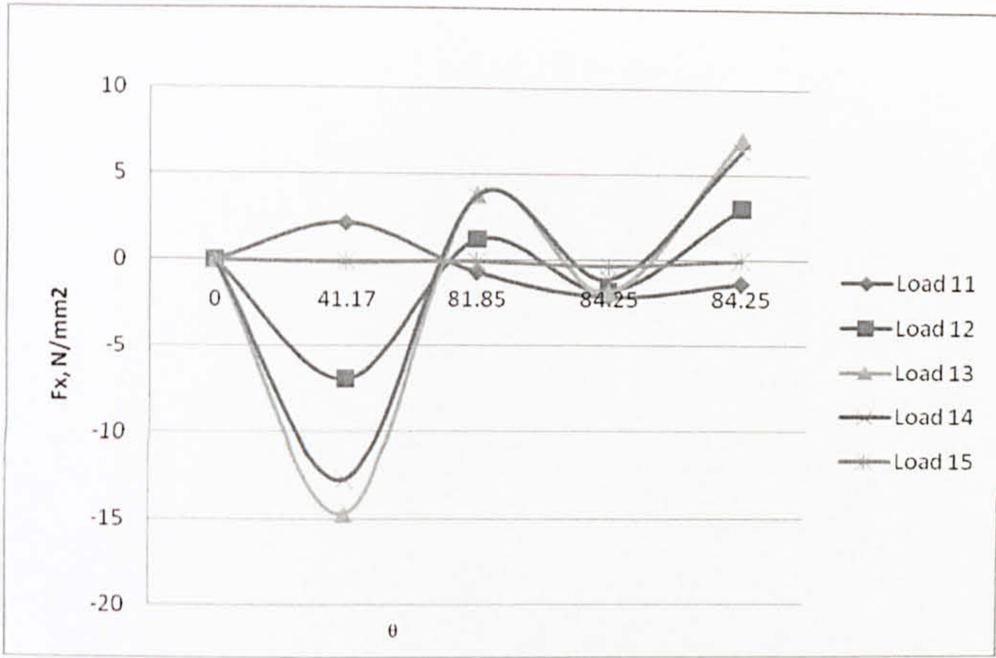
APPENDIX E.3: Platform BNVA (Joint 6110)



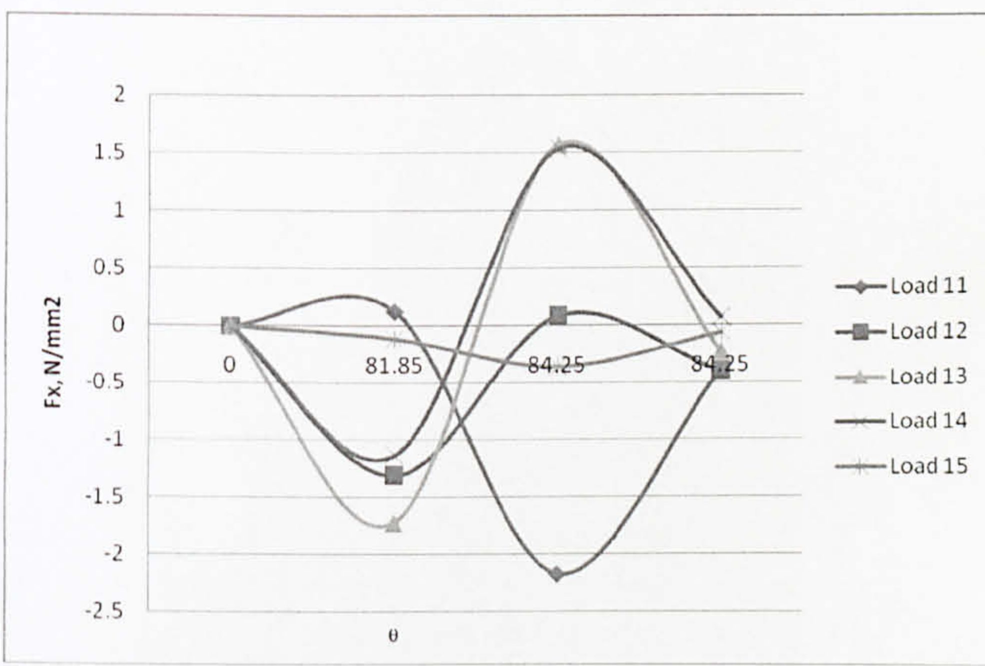
Axial Stress vs Brace Chord Angle for Original Joint 2130 (KT)



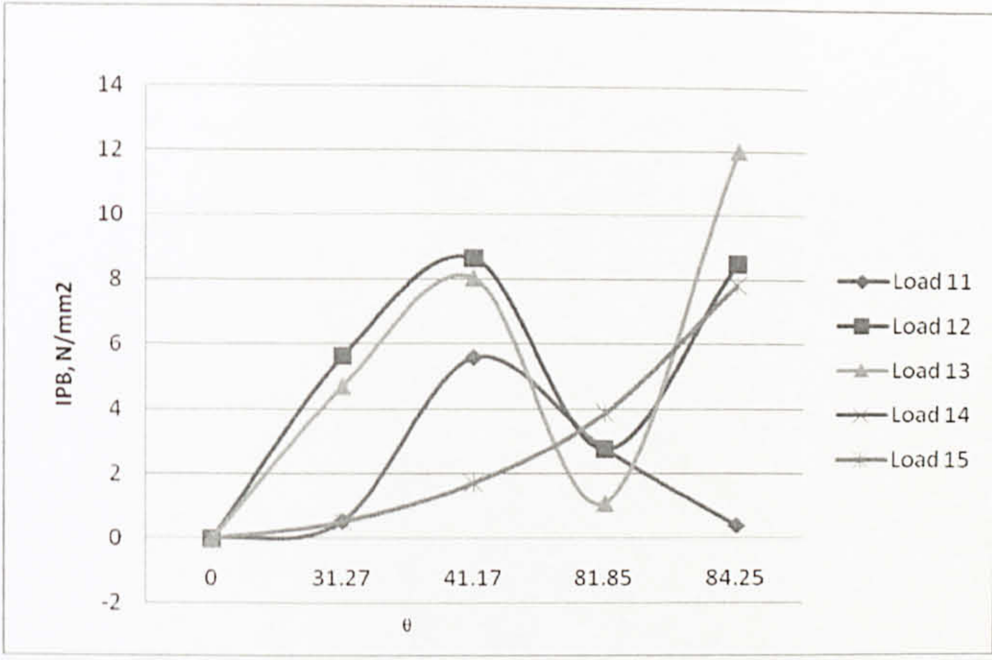
Axial Stress vs Brace Chord Angle for Modified Joint 2130 (KT-K)



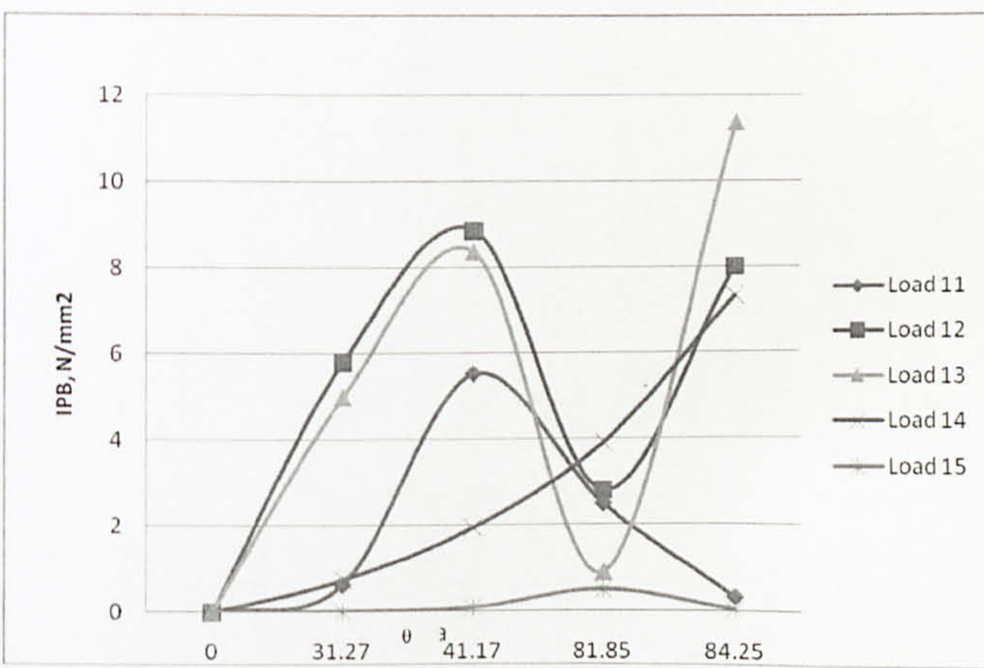
Axial Stress vs Brace Chord Angle for Modified Joint 2130 (KT-N)



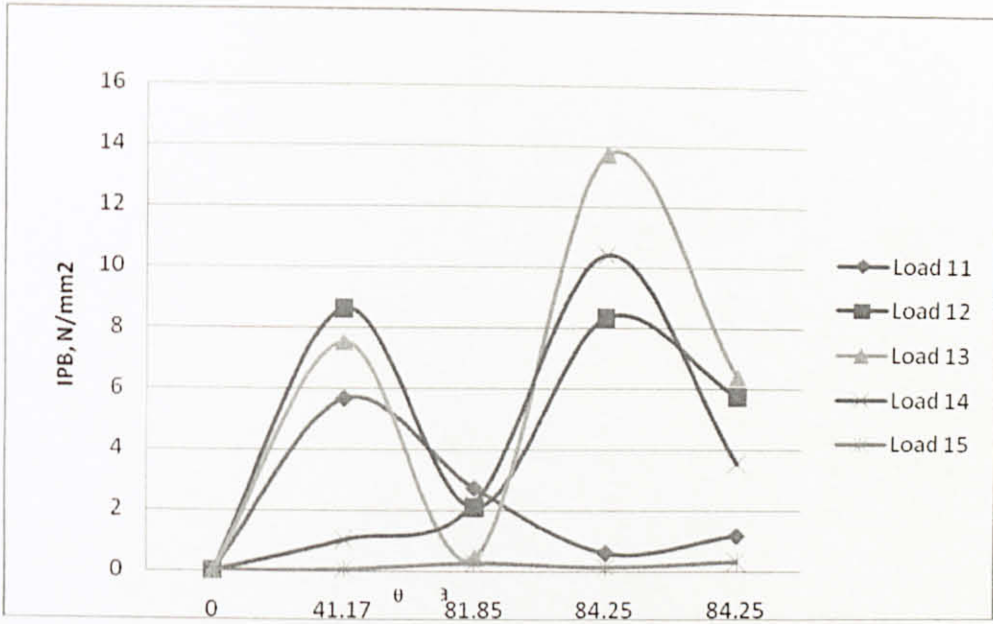
Axial Stress vs Brace Chord Angle for Modified Joint 2130 (KT-N)



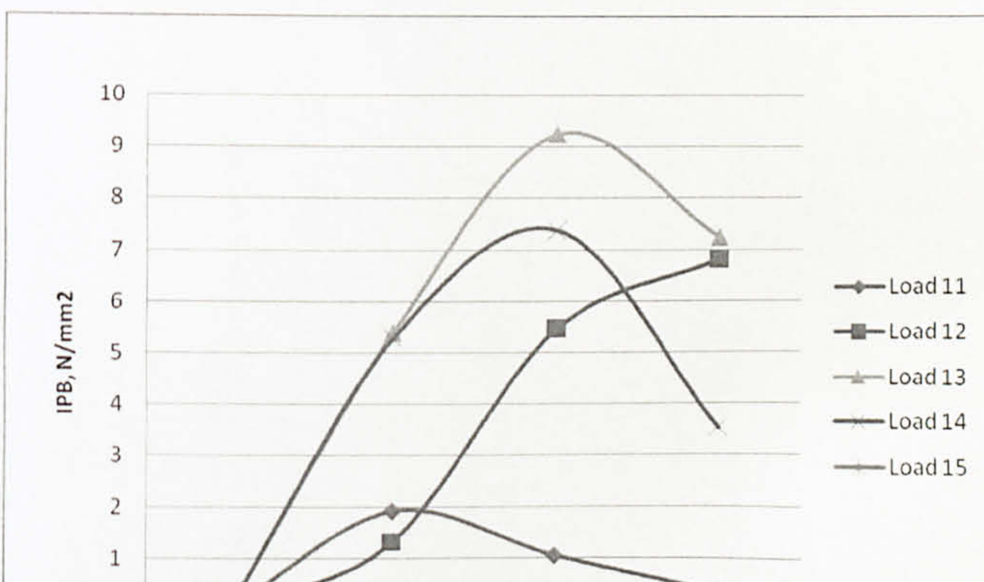
Out of Plane Bending vs Brace Chord Angle for Original Joint 2130



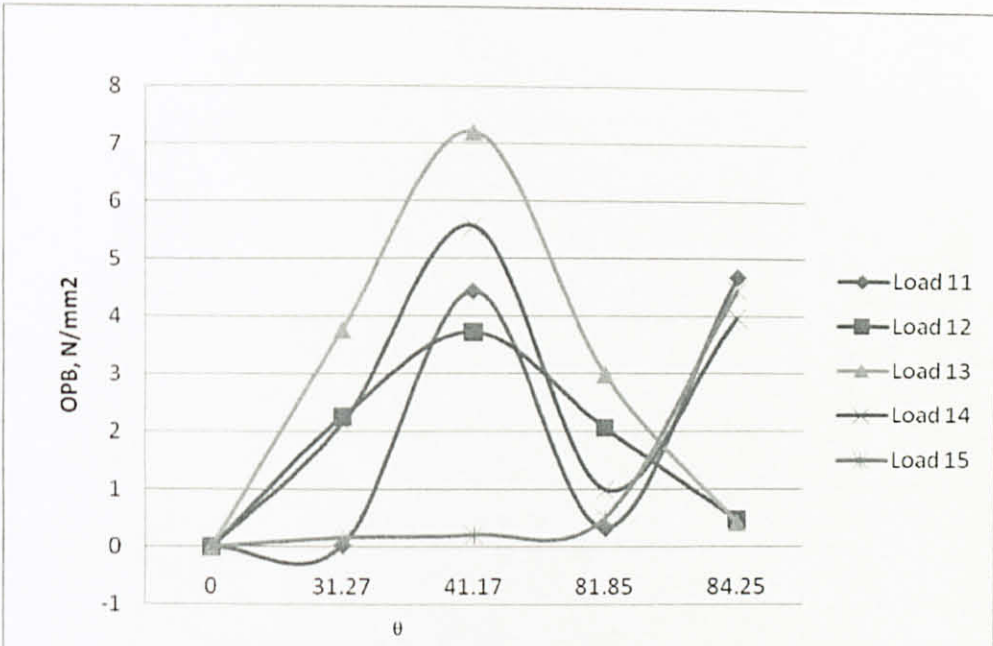
Out of Plane Bending vs Brace Chord Angle for Modified Joint 2130 (KT-K)



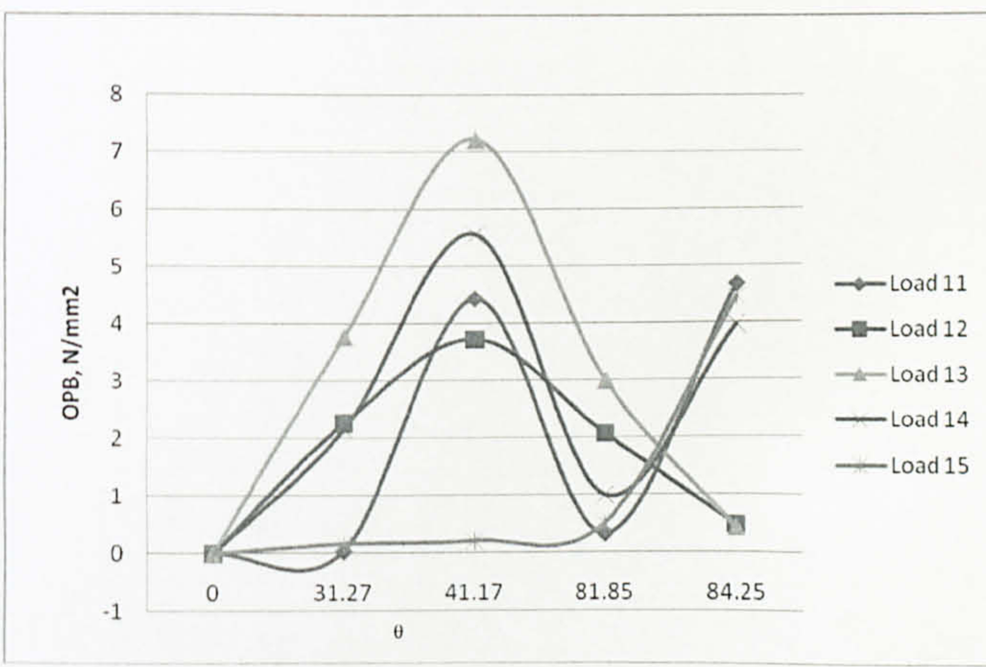
Out of Plane Bending vs Brace Chord Angle for Modified Joint 2130 (KT-N)



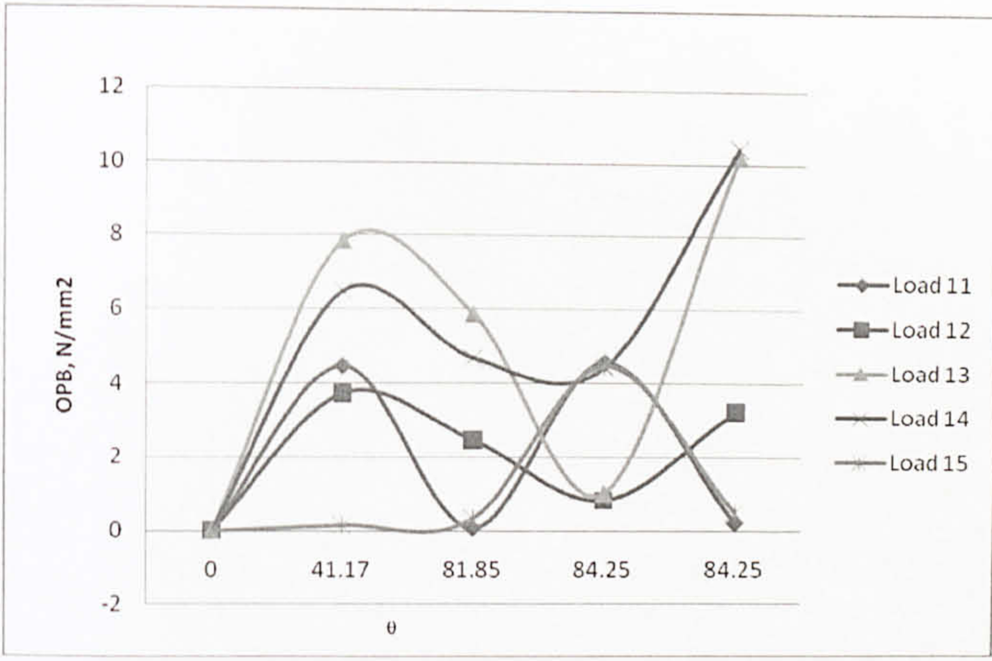
Out of Plane Bending vs Brace Chord Angle for Modified Joint 2130 (KT-T)



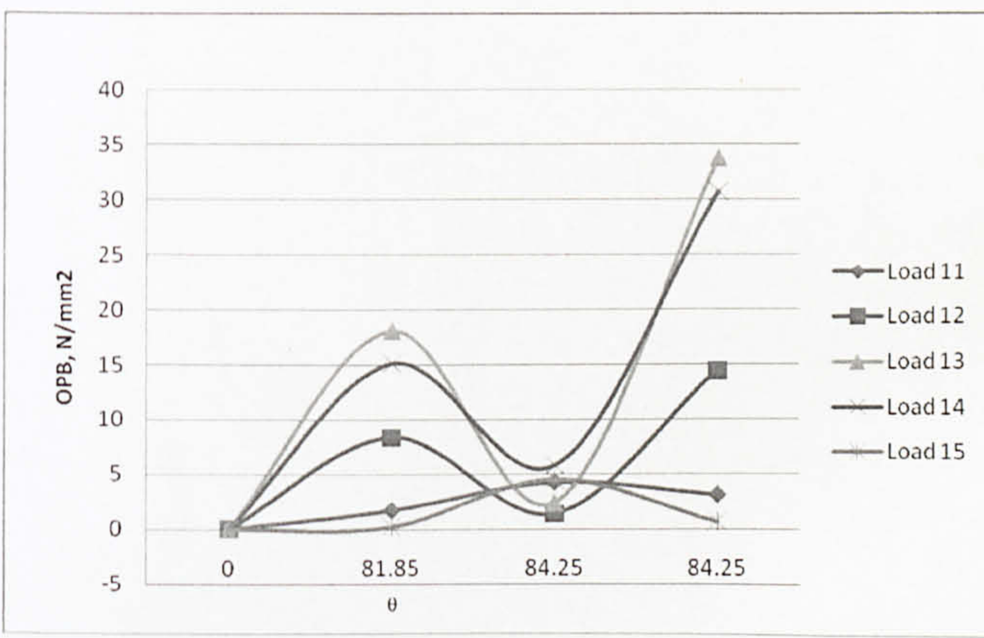
In Plane Bending vs Brace Chord Angle for Original Joint 2130 (KT)



In Plane Bending vs Brace Chord Angle for Modified Joint 2130(KT-K)

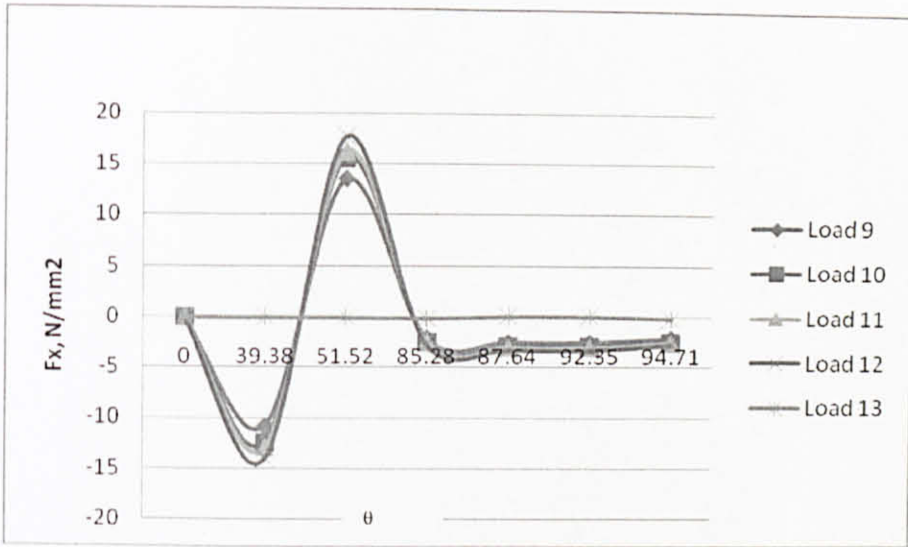


In Plane Bending vs Brace Chord Angle for Modified Joint 2130(KT-N)

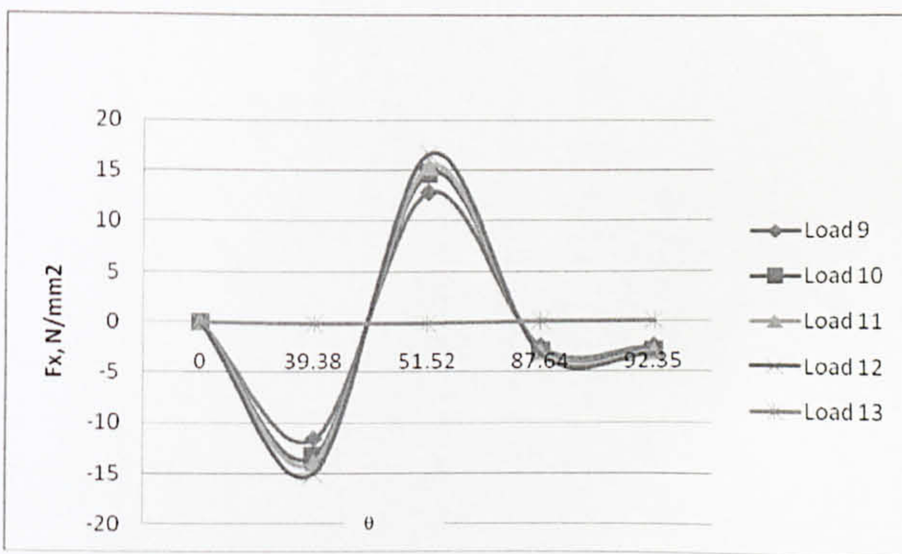


In Plane Bending vs Brace Chord Angle for Modified Joint 2130(KT-T)

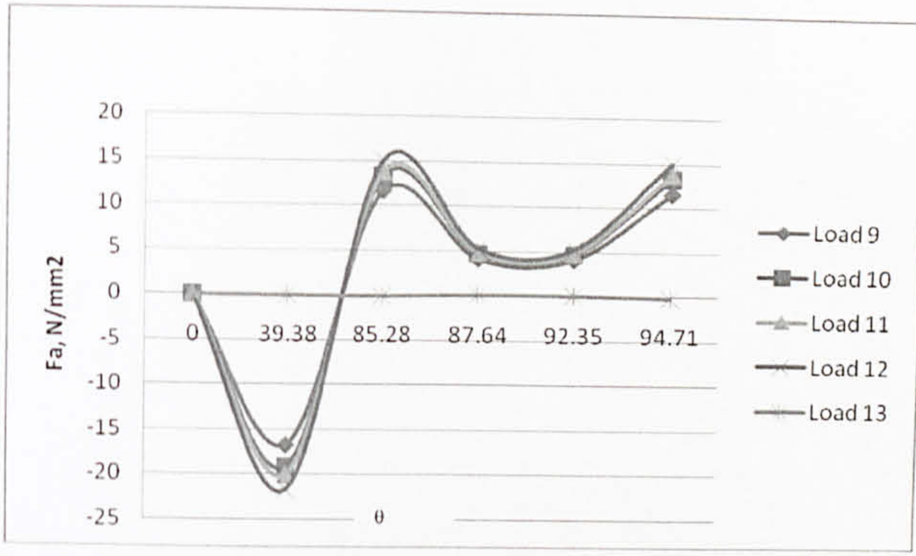
APPENDIX E.3: Platform BNVA (Joint 6110)



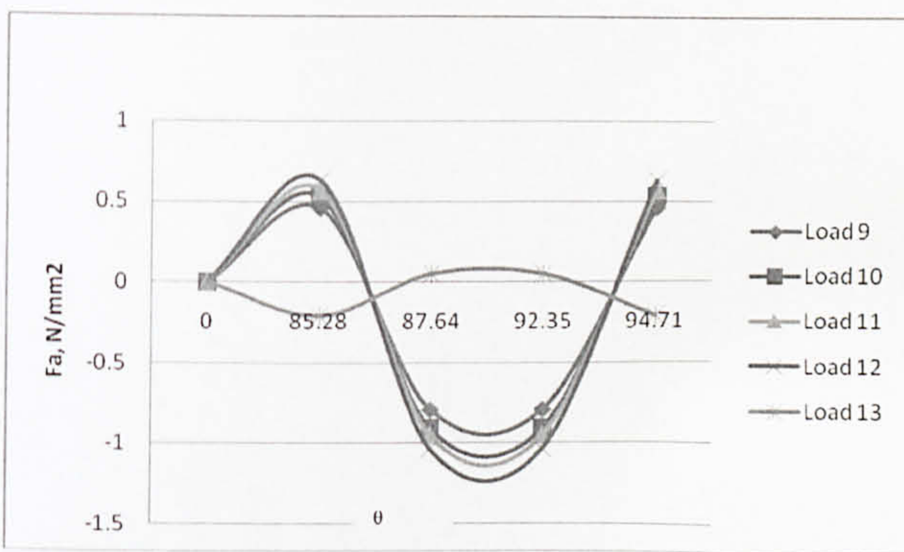
Axial Stress vs Brace Chord Angle for Original Joint 6120



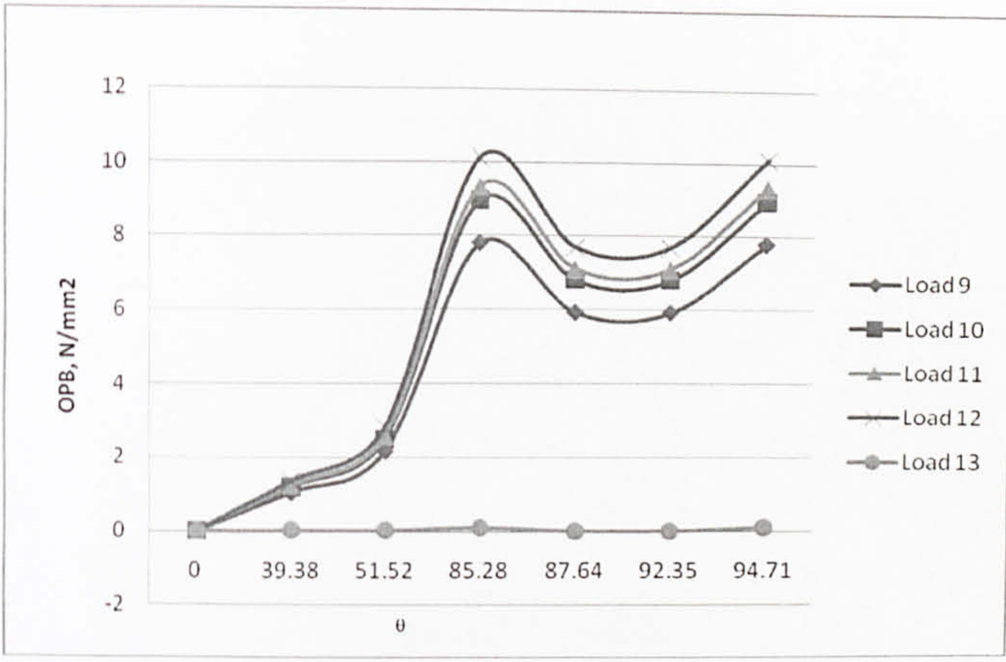
Axial Stress vs Brace Chord Angle for Modified Joint 6120 (KT-K)



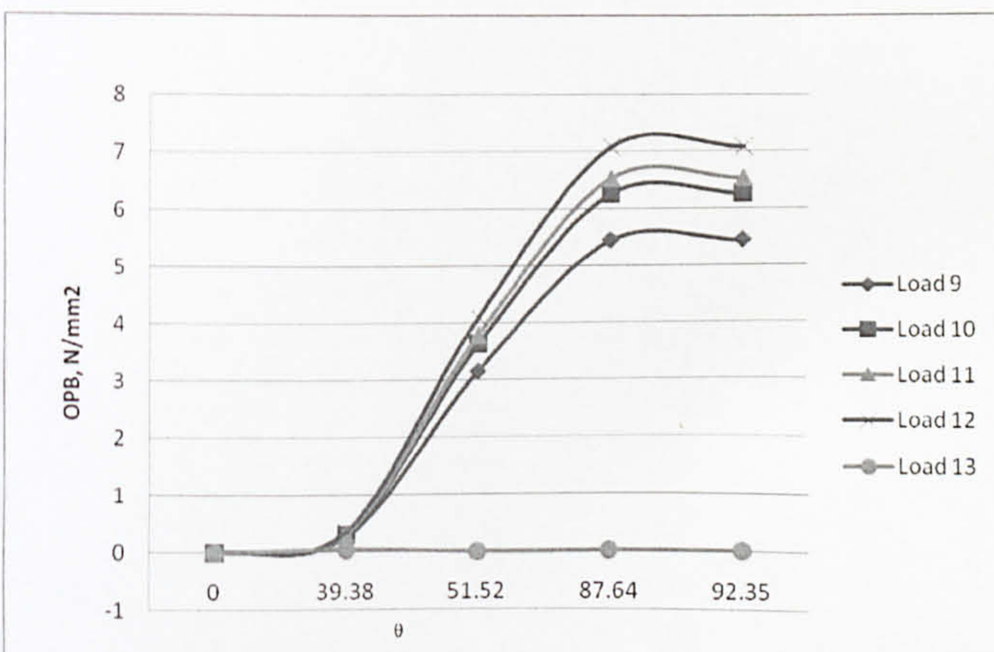
Axial Stress vs Brace Chord Angle for Modified Joint 6120 (KT-N)



Axial Stress vs Brace Chord Angle for Modified Joint 6120 (KT-T)



Out of Plane Bending vs Brace Chord Angle for Original Joint 6120



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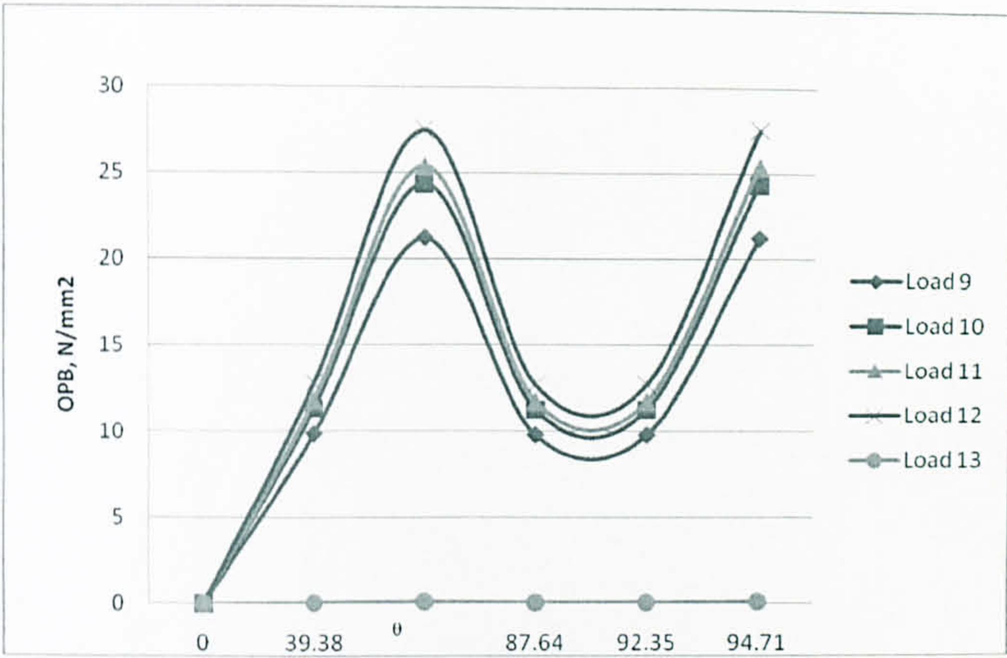

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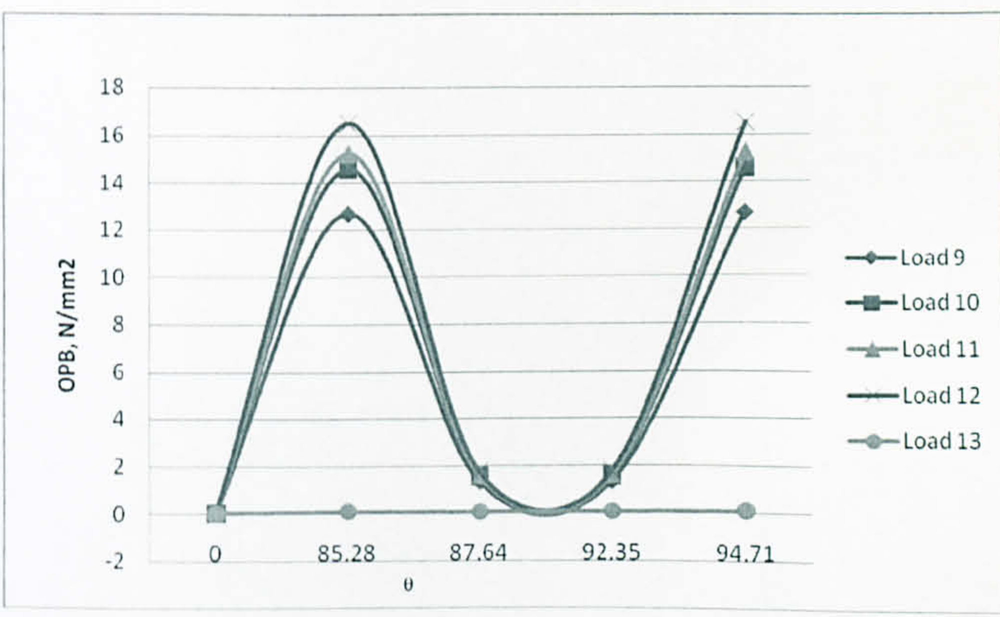

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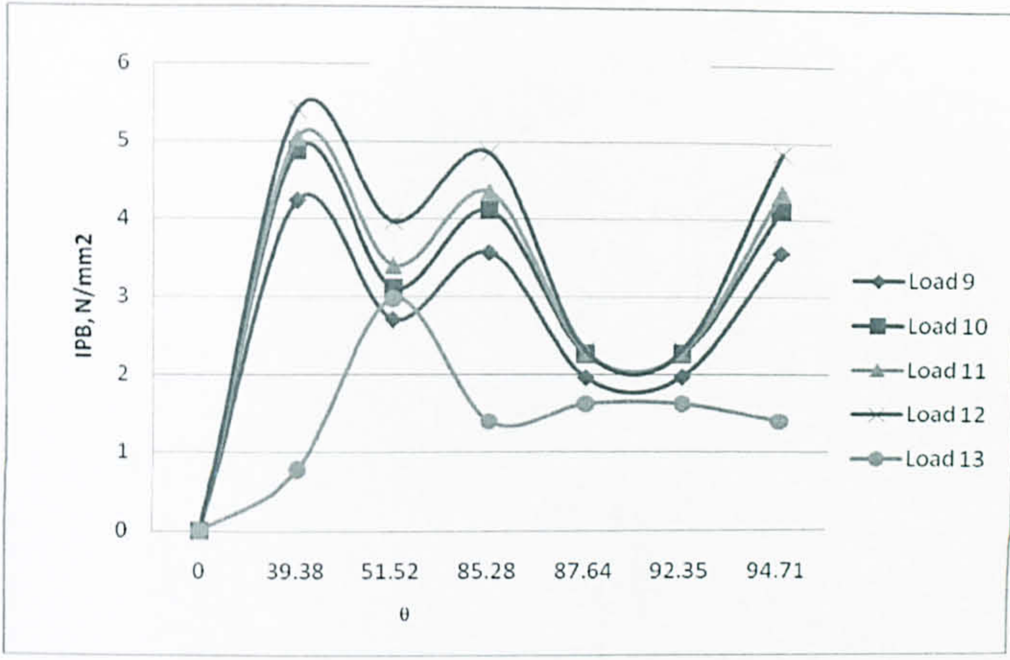
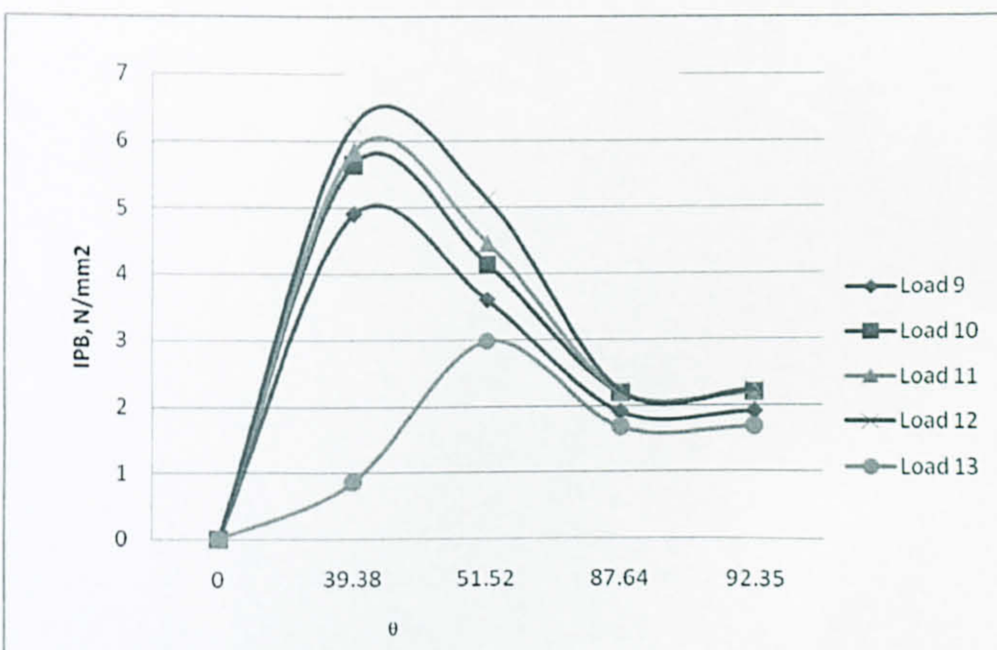
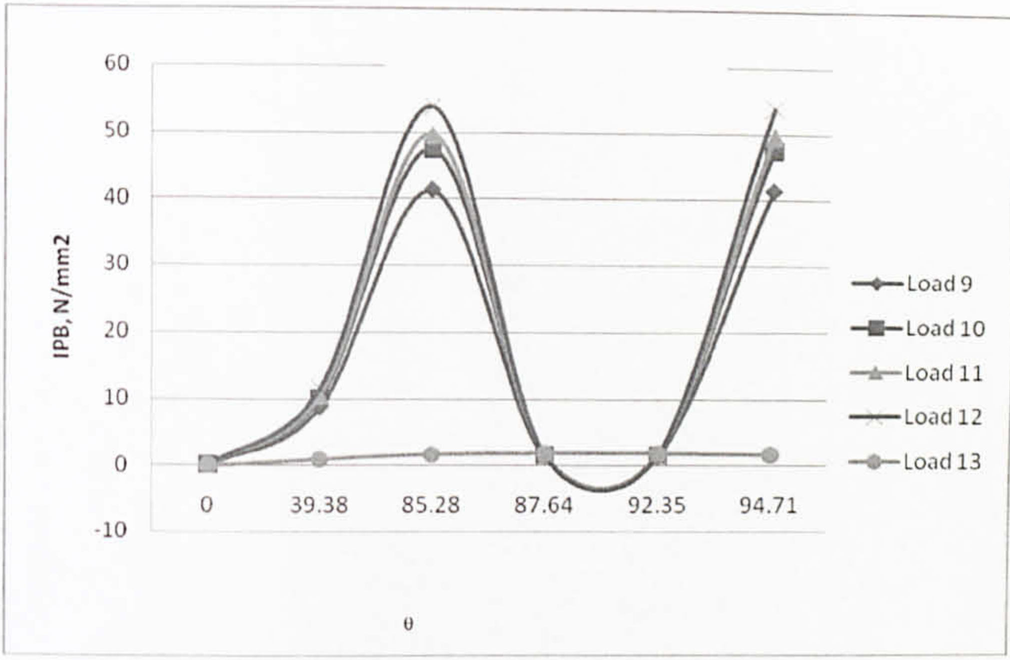


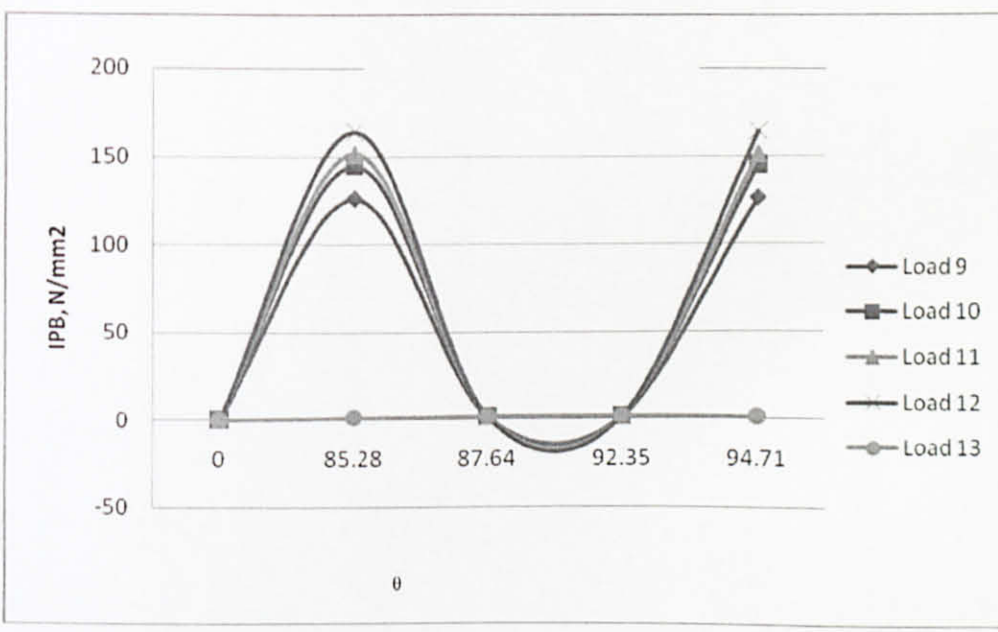
In Plane Bending vs Brace Chord Angle for Original Joint 6120



In Plane Bending vs Brace Chord Angle for Modified Joint 6120 (KT-K)

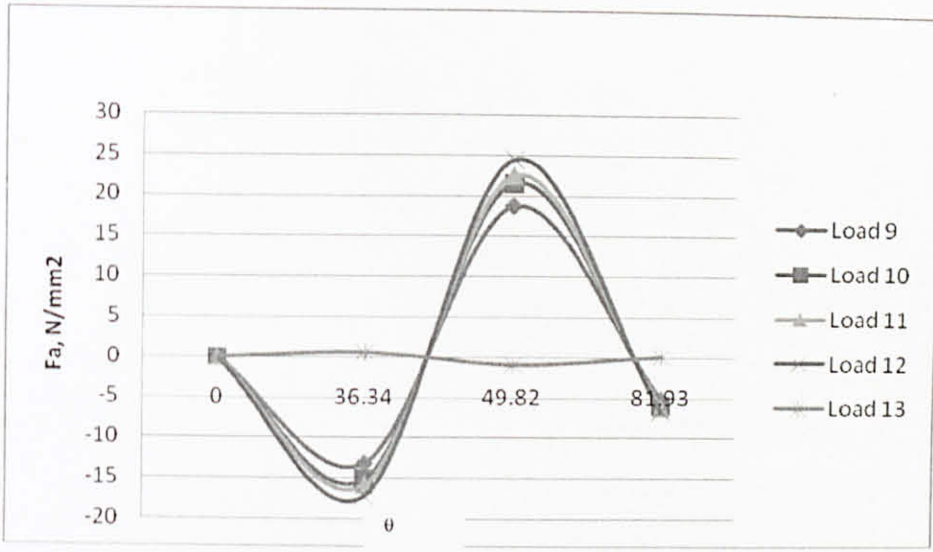


In Plane Bending vs Brace Chord Angle for Modified Joint 6120(KT-N)

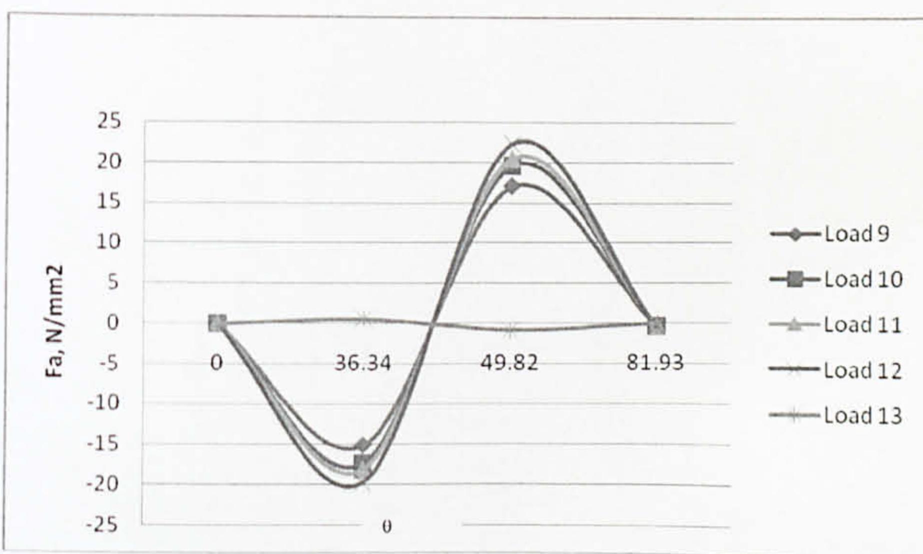


In Plane Bending vs Brace Chord Angle for Modified Joint 6120(KT-T)

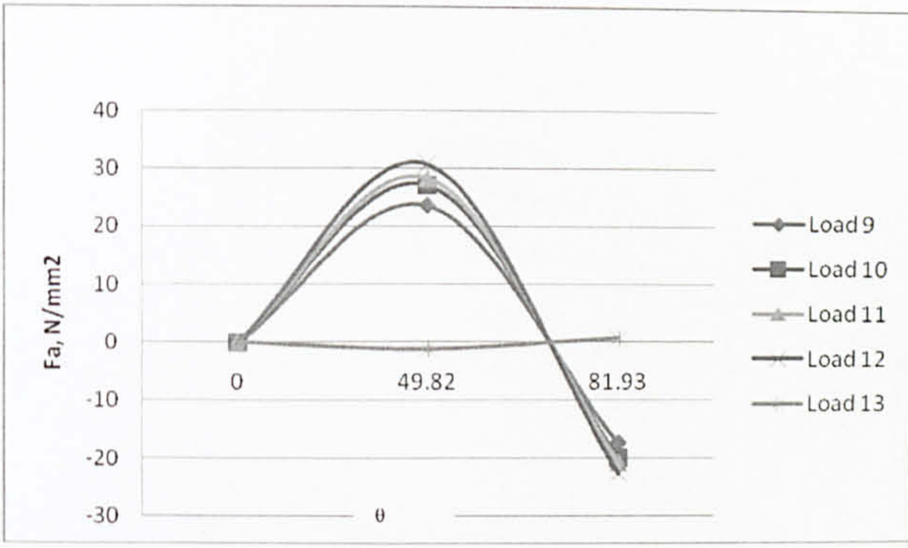
APPENDIX E.4: Platform BNVA (Joint 5130)



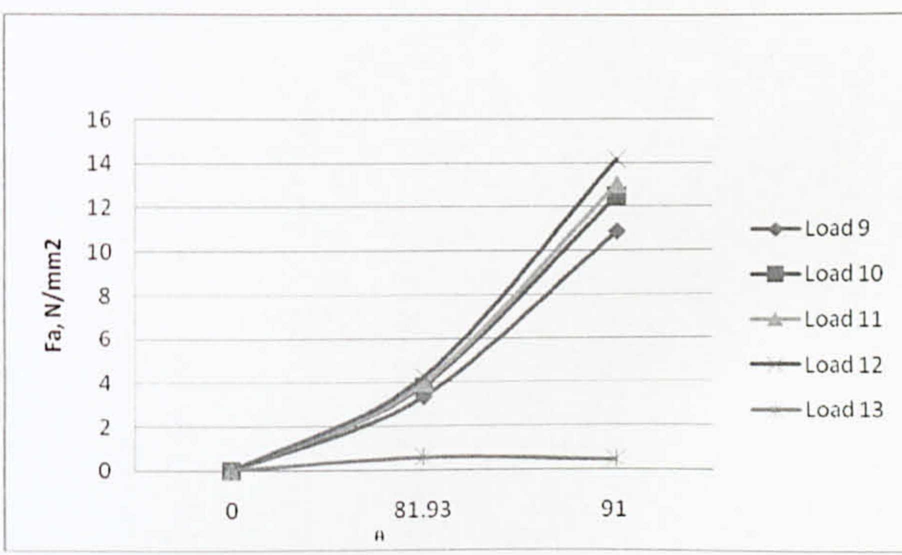
Axial Stress vs Brace Chord Angle for Original Joint 6120



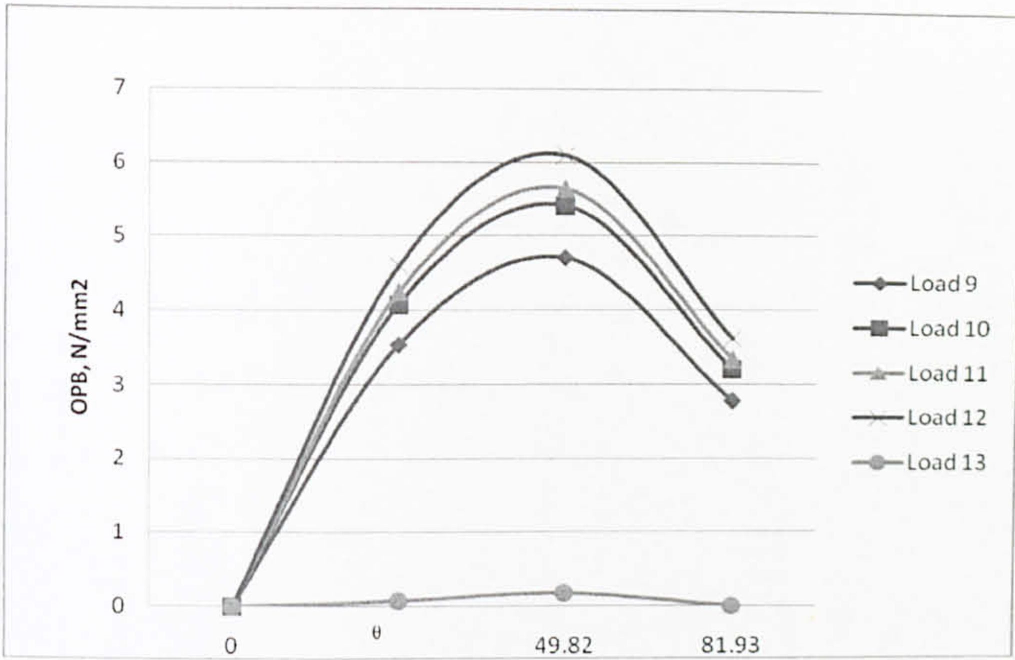
Axial Stress vs Brace Chord Angle for Modified Joint 6120(KT-K)



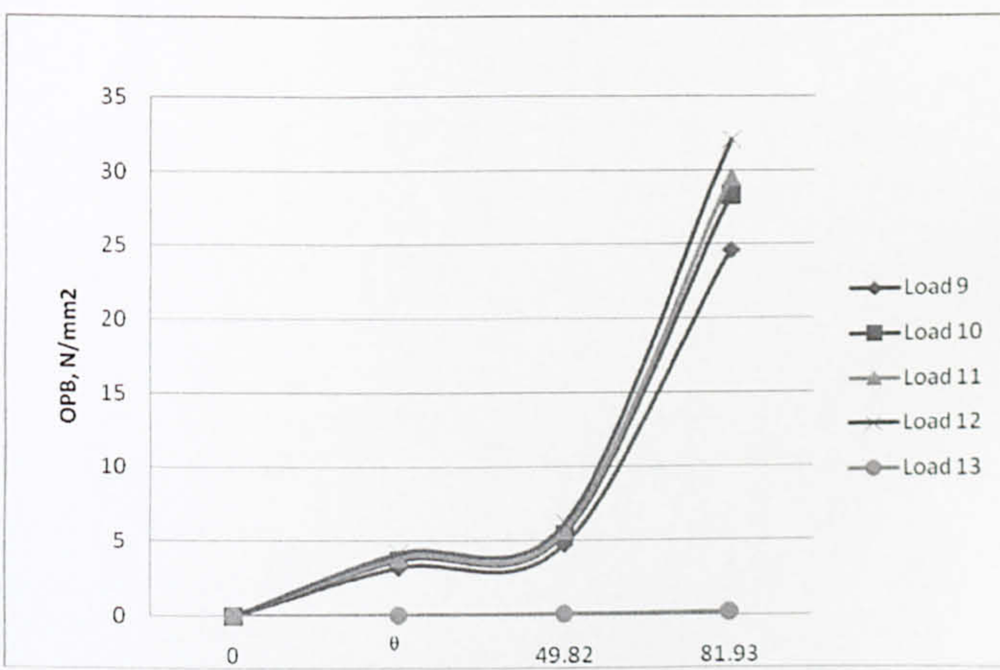
Axial Stress vs Brace Chord Angle for Modified Joint 6120(KT-N)



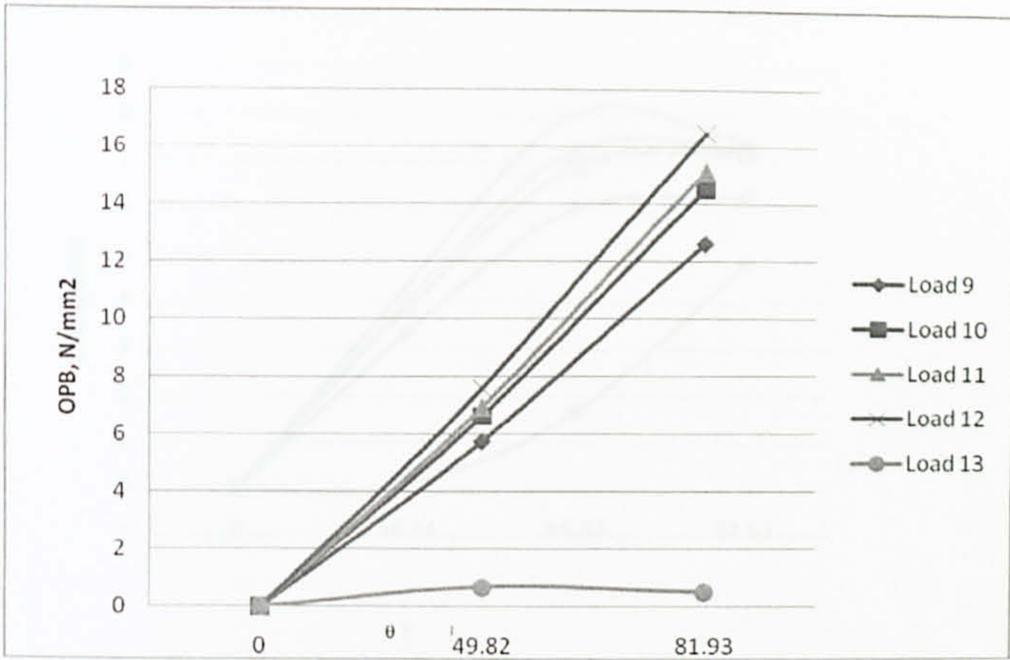
Axial Stress vs Brace Chord Angle for Modified Joint 6120(KT-T)



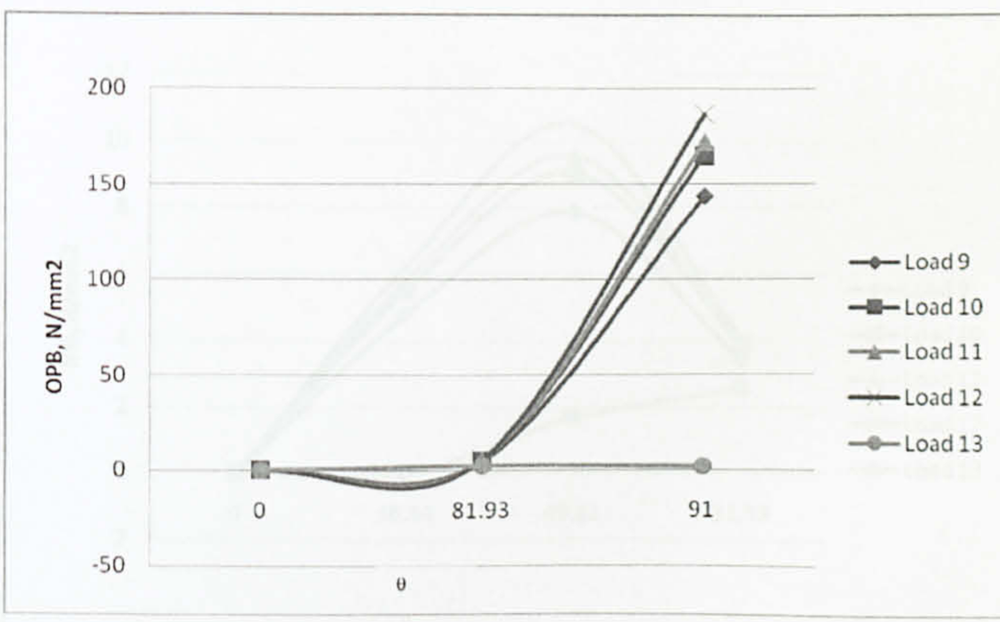
Out of Plane Bending vs Brace Chord Angle for Original Joint 6120



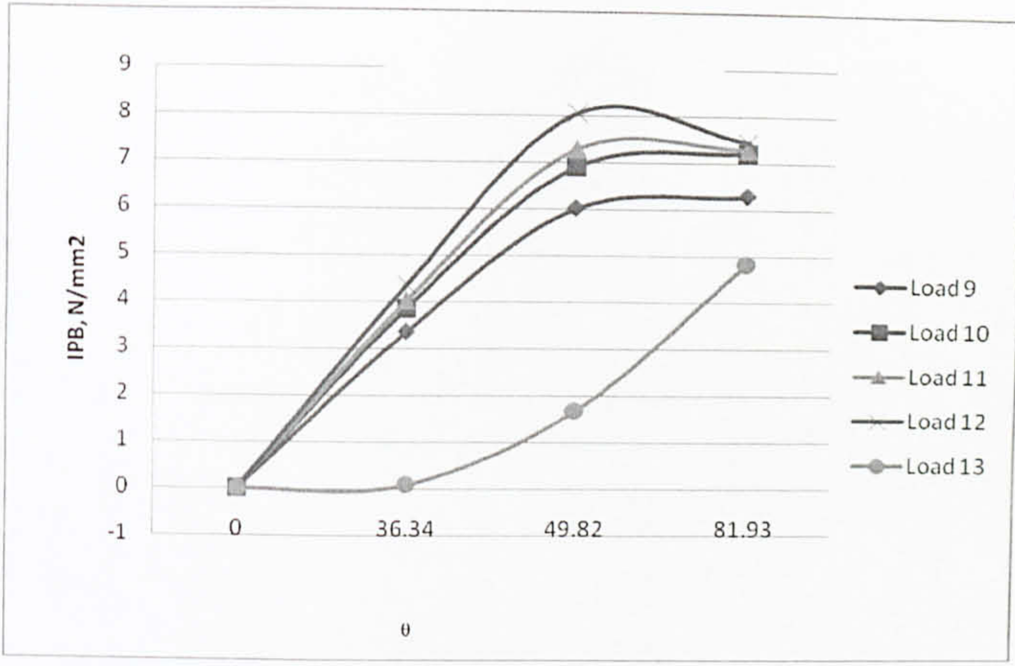
Out of Plane Bending vs Brace Chord Angle for Modified Joint 6120(KT-K)



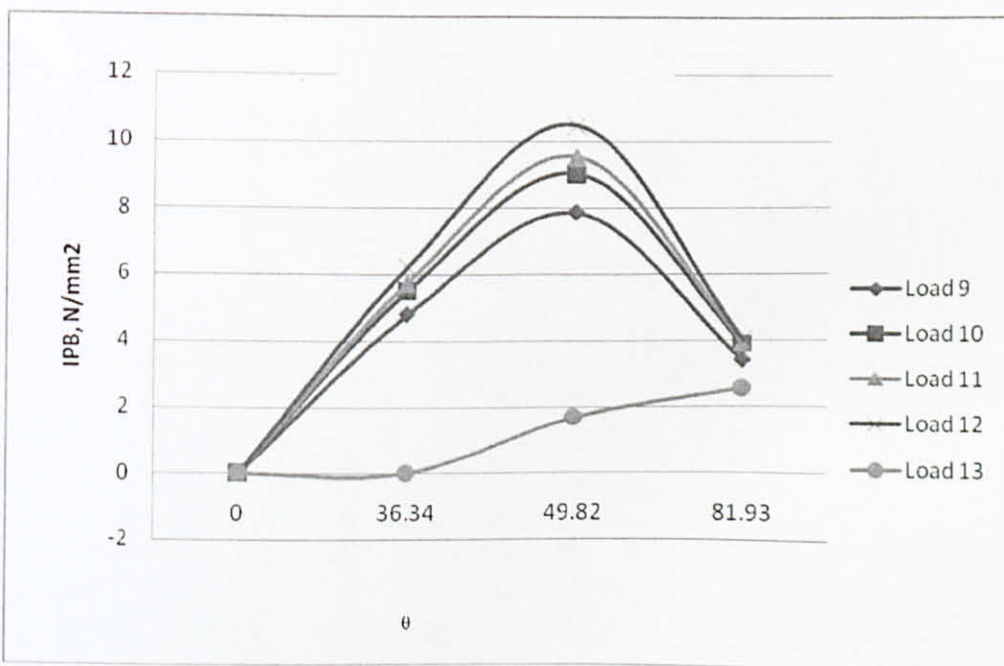
Out of Plane Bending vs Brace Chord Angle for Modified Joint 6120(KT-N)



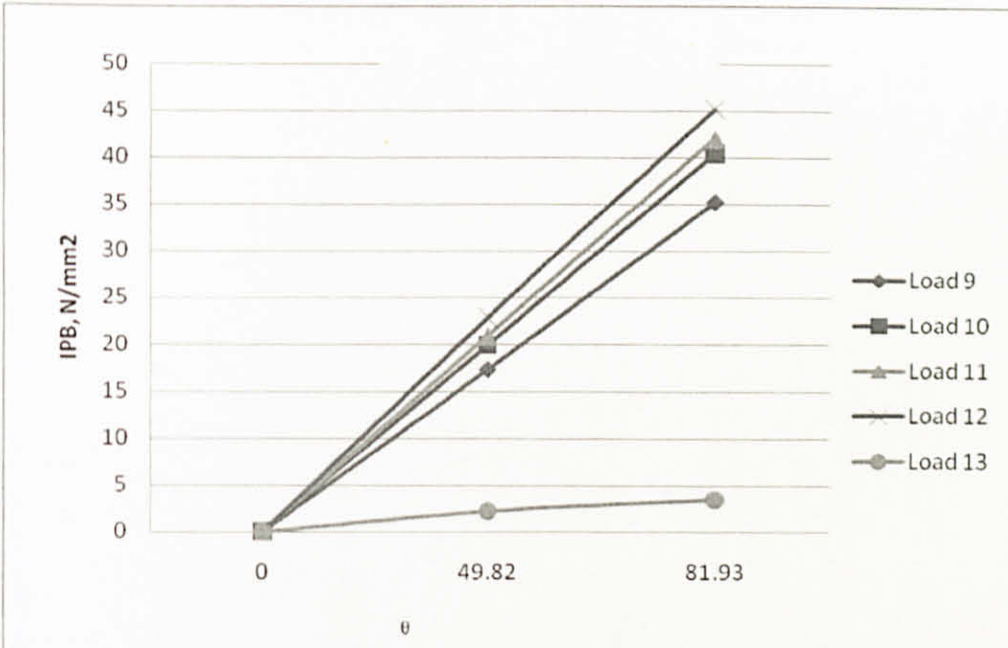
Out of Plane Bending vs Brace Chord Angle for Modified Joint 6120(KT-T)



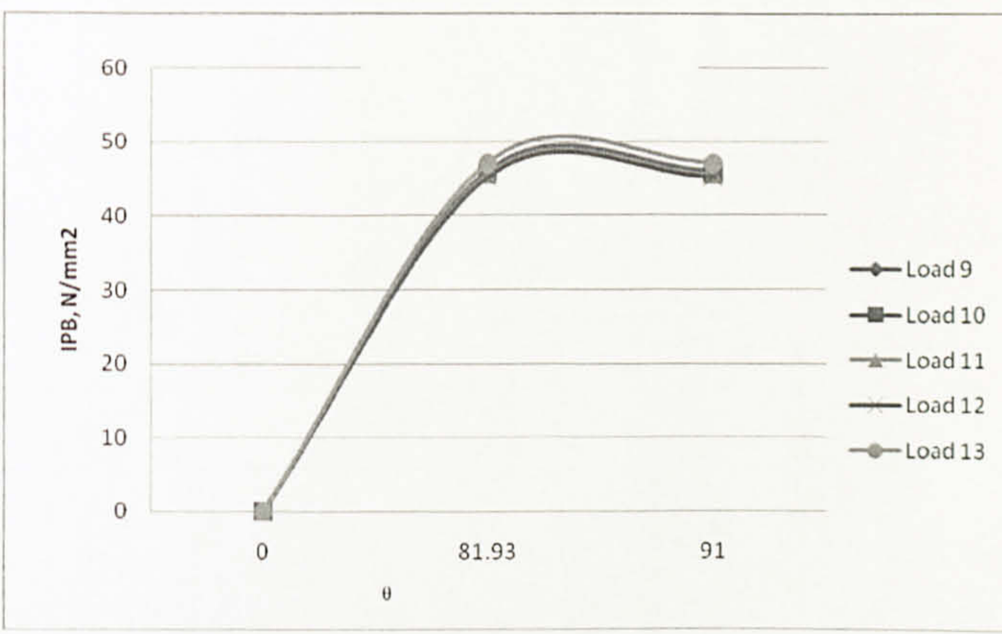
In Plane Bending vs Brace Chord Angle for Original Joint 6120



In Plane Bending vs Brace Chord Angle for Modified Joint 6120 (KT-K)



In Plane Bending vs Brace Chord Angle for Modified Joint 6120 (KT-N)



In Plane Bending vs Brace Chord Angle for Modified Joint 6120 (KT-T)